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An Oceanographic Study in the East Sea (the Sea of Japan)

— Korea and Russia cooperative research —

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제 출 문

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SUMMARY

I. Title

An Oceanographic Study in the East Sea(the Sea of Japan)
-Korea and Russia cooperative research-

II. Significance and Objectives of the Study

The offshore of the Korean Peninsula in the East Sea(Sea of Japan) is important to understand the fundamental problems on the origin and the evolution of the East Sea as well as to search for the various kinds of mineral resources. The Ulleung Basin has a drastic tectonic situation to understand the East Sea with respect to the Japan Basin or Yamato basin because it is situated nearby Korean Peninsula extended to the continental crust and bounded by Tsushima-Korea straits to the southwest and by Kyushu to the south-southwest directions and by the Korea Plateau to the northwest composed of continental crust.

According to accumulated study in the East Sea number of speculative models have been postulated for the origin of the Japan Sea. Three group of models can be summarized: (1) oceanization or crustal thinning, (2) entrapment of ocean basin, and (3) ocean floor spreading associated with relative continental drift. Based on the recent evidences with deep crustal structure by OBS, direct drilling, seismic profiling, analysis of magnetic anomaly, etc. the first and second models are likely to be abandoned because the crucial evidences on their realization are not definitely secured. Consequently the opening models are the most popular but the ages and modes of opening are still under discuss.

The Ulleung basin, especially, in the East Sea is one of the major basins in the East Sea which is assumed to have valuable clues on the understanding of the formation of the East Sea. Nevertheless the Ulleung basin are less studied relative to other area of the East Sea. Ruogh-spaced seismic reflection survey excuted by the Korea Petroleum Development Corporation (PEDCO) was only the deep seismic reflection survey by large volume air-gun in the Ulleung Basin which can provide the deep structure of the basin.

The recent geophysical researches on Yamato Basin located at the east of the Ulleung Basin by Japanese scientists show that there are still some problems to fit the ideas of plate tectonics to the origin and evolution of this region. According to those results the Yamato Basin have been formed by mechanism of the stretching of the earth's crust due to rifting process which is accompanied with the uplift of hot mantle plums and the extension of environment on the basement level. However still many evidences are necessary to apply the theory of plate tectonics to geohistory in the East Sea and especially the origin and the evolution of the Ulleung Basin must be clear identified.

This study aims at defining the structure of the Earth's crust and the crucial distributions of the velocity properties along acoustic basement in the Ulleung Basin and its landward transient area based on the geophysical data such as seismic refraction and reflection data, gravimetric, magnetic, heat flow as well as geological and paleomagnetic study in the Dok Islands. One of the most significant goals is to provide crucial results in order for solving the origin and formation of the East Sea.

III Scope of the Study

The Korean-Russian cooperative cruises using R/V Morskoy Geophysics and R/V Prof. Gagarinsky which was provided during August to September of 1991. Subsequently in 1993 R/V Morskoy Geophysics conducted the geophysical survey with several research items in the Ulleung Basin and on offshore of the eastern coast of Korea.

In the survey a total of 30 OBSs (Ocean Bottom Seismometers) were deployed to cover the whole study area. 3660 in3 air gun was used as a seismic soure which is expected to generate seismic waves sufficient for investigation of the deep structure. Single channel sparker profiling was also conducted using a 12 - 14 Kjoule sparker along the cross configuration and complementary lines as well to acquire the geologic structure to the acoustic basement that can serve in refining the upper structure of the Ulleung Basin. In the survey of 1993 gravimetric, electromagnetic, geothermic experiments, geological and paleomagnetic study in the Tokdo as well as seismic refraction method were added.

Heat Flow (HF) measurements are produced by original IMGG equipment providing directly measurements of temperature gradient in subbottom sediments and definition of thermo-conductivity of deposit sample been using piston-core operations. The stations of HF was placed along seismic Lines I and II; distance between neighbor stations fitted just closely about 10-15 nautical miles. The digital measuring equipment for geomagnetic research (DMEFGR) was used to automatically measure the electromagnetic field variation onshore. Gravity data was analyzed to model the Earth's crust based on seismic data and heat flow data. The petrography, geochemistry and paleomagnetism of Dok Island volcanic rocks was also studied.

The preliminary interpretation of the OBS's record sections was performed by use of arrival times and slopes of the first break in combination with the amplitude analysis. These measurements were used to construct the approximate geologic structure of the crust. The ray-tracing algorithm was incorporated in the determination of the appropriate crustal structure and the depth to the Moho discontinuity.

The recorded seismic signals contain the information on the deep crust and Moho, thus the structure of the Ulleung Basin was, for the first time, investigated to the depth of about 20 km.

IV. Results of the Study and Further Suggestions

The cooperative research program of Korea and Russia has taken concrete on the deep crustal structure of the Ulleung Basin in the East Sea from seismic reflection profiling, gravity, geomagnetism, geothermics as well as seismic refraction with OBS's.

The results obtained in this study can be summarized as follows:

1) The thickness of the crust along Line I varies from 21 to 25 km on the southwestern edge 15-17 km to 15-17 km on the northeastern one. The velocity along the Moho discontinuity varies from 7.93 km/sec unlder the Ulleung-Dok islands volcanic area to 8.0-8.16 km/sec under non-volcanic parts of the line.

2) Beneath the Moho discontinuity of Line I, the refracting medium are attributed to a relatively small velocity gradient around 25-35 km depth. The gradient will be changed due to the existence of the thickening low velocity zone. The structural features which have

been revealt along Line II are similar to that of Line I.

3) Gravimetric study and heat flow exploration show existence of the low density layer over the depth of 30 to 60 km around the southern part of the East Sea. Besides, topography-gravity relation shows that Korean Peninsula is in isostatic equilibrium except the southeastern part.

4) The magnetization of Cenozoic basalts of Ulleung Basin is 2.56-5.73 A/m, and the value of remanent magnetization ranges from 1.35 A/m to 1.45 A/m. The level of this values is much lower if the absolute age of basalt increases.

5) The topmost crust structure of the Ulleung Basin is similar to that of Korean Peninsula but the lowermost of it is rather similar to that of the Yamato Basin. The principal features of the crust show the tracks of ancient geohistory and the newest geodynamic processes.

6) Petrography, geochemistry and paleomagnetism of Dok Island volcanic rocks are analyzed. The evolution process of volcanic rocks show a tendency to repeat from basalt, trachyandesite to trachyte. The volcanic rocks from Dokto are alkali-Oceanic-Island Basalts different from island-arc basalts. The paleomagnetic data shows strong normal and reversal magnetism.

With the above identification of the the deep structure of the Ulleung Basin through the current study, the future work will be concentrated on construction of the detailed crustal structure of the assumed trasitional area between the East Sea and the Korean Peninsula.

The existence of the low density mantle around the southern part of the East Sea requires more detailed study on not only lithospheric flexure but with mantle convection over the Korean Peninsula. The long term seismological, geothermic observations with gravimetric study is suggested.

Althogh Korea and Russia cooperative expedition was successfully conducted, the detailed deep structure of the East Sea near the Korean Peninsula has not been fully understood in spite of its importance to descriptions of the formation of the East Sea within the general framework of plate tectonics. Therfore it would be desirable to make researches in cooperation with Russia and Japan that have accumulated more scientific results and experiences in this area.

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Key: 1. Major deep-seated fault; 2. Infered extension of the major deep-seated fault; 3. Area with "suboceanic crust" ("basaltic" layer); 4. Depth of contour of the surface of "suboceanic crust" from the sea level in km; 5.Tertiary and Quaternary volcanic island or submarine rise; 6. Active seismic zone with deep earthquake foci(300 to 450 km); 7. Late Paleozoic granitic rock; 8. Late Cretaceous granitic rock; 9. Archean on land; 10. Proterozoic and possible Proterozoic on land; 11. Archean and Proterozoic metamorphic and granitic rock; 12. Permian and Paleozoic marine sediment; 13. Upper Cretaceous and Paleogene sediment; 15. Proposed spreading center based on magnetic anomalies (Isezaki,1975). (Constructed by Choi,1983)

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A number in the circle:

1-foreshore anticlinorium of Sikhote-Aline; 2-main anticlinorium of Sikhote-Alin; 3-main synclinorium of Sikhote-Alin; 4-Alchan trough; 5-Hankay massif; 6-Daubikhin trough; 7-Sandagou marginal depression; 8-Suyfun through; 9,10-Suputin trough; 11- Suchan -Sudzikhin anticlinorium; 12-Tumangan folded zone; 13-Kvanmo massif (K-Kamtchak massif); 14-Ammokan trough; 15-Khasan-Rivon trough; 16-Khannim massif; 17-Pkhemam trough; 18-Keaungy massif; 19- Ogcheon trough; 20-Sobecmassif; 21-piedmont Scushima trough of Sacav geosyncline; 22-Khida belt; 23-Khida massif; 24-Tuvou folded zone; 25,26- Tugouku folded zone; 27-Rakeau folded zone; 28-Sambagava folded zone; 29-Titibu folded zone; 30-Simanto folded zone; 31-Nakamuro geosyncline; 32 -Kanto trough; 33,34-Kitakami folded zone; 35-Khidaka main belt; 36- West-Sakhalin synclinorium; 37-East-Sakhalin block zone; 38-Peter Great bay; 39-shelf and continental slope of Korea; 40-Near-Korean zone; 41-shelf and slope of the Japan Islands and Sakhalin Island; 42-Bogorov Rise; 43-central deep depression; 44-ridges of Yamato Rise; 45-deep-water part of Khonsu depression; 46-Foreshore falt; 47-South Sikhote-Alin fault; 48-Shore geosuture of Sikhote-Alin; 49-Median fault; 50-Fossa Magna fault zone.

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Fig. 5. Morphotectonic Map of Southern part of East Sea.

Scale 1:500,000

Authors V.P. Semakin and A.S. Svarichevsky.

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Marked by the numbers; 1-Ulleung basin; 2-Korea penincula rise ; (3-8)-the complicated underwater rise of the Korea plateau; 3-Wonsan plateau rise; 4-Ulleung plateau; 5-rise to the west from Ulleung island; 6- Wonsan trough; 7-Ulleung trough; 8-Mikho plateu; 9-Oki rise.

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Fig. 10. Seismic section of Line I.

Key: (see Fig.11)

Fig. 11. Seismic section of Line II.

Key: 1-reflectors got from single channel seismic profiling; 2- reflectors with the values of its velocities; 3-Paleozoic basement; 4-acoustic basement may be Neogene; 5-Moho discontinuity; 6-thrust and fault zone; 7-interfaces of vertical change of seismic velocities; 8-zone of qualitative changes of sediment cross section; 9-positions of OBS; 10-position and number of heat flow stations; 11-the interface depth values in the intersection of the profiles, 12-isotherm, 13-the region of higher temperatures, 14-the layers of high conductivity.

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KOREAN SCIENTIFIC RESULTS

PART I-1

한국해양연구소 부문

제 1 장

서　　　론

제 1 장 서　론

동해는 태평양 판을 비롯해서 필리핀 판, 유라시아 판, 오호츠크 판등 수 개의 판등이 복합적으로 작용하는 배호상 분지(back-arc basin)로서, 일본분지, 야마토분지와 울릉분지등 세개의 심해분지와 한국대지, 야마토 해령, 울릉해령, 오키뱅크등 해저고지형등으로 이루어져 있다.

동해 퇴적기반은 주로 대륙연변, 융기된 대륙지각이나 해양지각으로 구성되어 있다(Tamaki,1988). 동해 대부분의 해저고지대는 대륙지각의 잔재들이나 심해분지 지역은 일부가 해양지각으로 이루어져 있음이 밝혀졌다. 일본분지는 심부 탄성파 굴절법 탐사와 자기이상의 분석을 통해서 전형적인 해양지각으로 확인 되었다(Ludwig, 1975; Tamaki, 1988). 그러나 야마토분지는 상부 및 하부지각의 탄성파속도 분포로써는 해양성이지만 지각의 두께가 통상적인 해양성지각보다 비정상적으로 두꺼우면서 자기이상도 매우 미약할 뿐만 아니라 해양지각의 확장에 따른 자기선구조도 밝혀지지 않아 아직은 일본해와 같이 뚜렷한 정의가 어려운 상태이다 (Chung, 1991).

동해의 지각구조나 생성 메카니즘을 비롯해서 아직 많은 논쟁의 여지가 남아 있는 생성 기원등을 밝히기 위해서는 이미 많은 연구결과가 축적되어 있는 일본분지나 야마토분지와 못지 않게 울릉분지에 대한 연구가 균형있게 이루어져야한다.

울릉분지의 지각구조를 조사하기 위해 한국해양연구소(KORDI)와 러시아 과학아카데미 소속의 Instititue of Marine Geology and Geophysics (IMG&G)가 공동연구로서 1991년 8월과 1993년 3월 두 차례에 걸처 해저면 지진계 (OBS)와 대용량의 에어건을 이용하여 탄성파 굴절법 탐사를 수행하였다. 이 연구에서는 울릉분지에서 모호면까지의 지각층서를 정확히 알고자 연속적으로 에어건을 발파함으로써 얻는 OBS자료를 처리하고 해석하는 기술 개발하에 중점을 두었다.

한편 해상중력 분야는 해양조사선 온누리호의 취항과 함께 동해지

각구조 및 생성기원 연구에 새로운 도구로써 강력하게 활용될 수 있게 되었다. 중력이상은, 주로, 지구내부의 밀도구조를 반영하며, 이에 따라 태평양이나 대서양 등 대양저의 해산, 해구, 해령, 해분와 같은 대규모 지질학적 해저구조를 밝힘으로서 plate tectonics 의 확립에 크게 기여하였다.

본 연구는, 해상에서의 중력 관측자료를 이용하여, 장기적으로, 한반도 주변해역에 있어서의 고정밀도의 중력이상, 지오이드의 기복을 결정하고, 이와 더불어 지구내부의 밀도구조, plate tectonics, geodynamics 등에 관련된 지질학적, 지구물리학적 연구 수행을 위한 포석을 마련하고 , 1993년 5월 동해 울릉해분 북부일원에서 조사선 온누리호와 L&R 사의 해상중력계를 이용하여 얻은 해상중력자료 처리 결과와 OBS에 의한 탄성파 굴절법 탐사자료, 탄성파 지층자료, 열류량 측정치 등을 종합적으로 분석하여 지질구조를 해석하는 데 목적이 있다.

제 2 장

해저면 지진계(OBS)를 이용한 울릉분지의 지각구조 연구

제 2 장 해저면 지진계(OBS)를 이용한 울릉분지의 지각구조 연구

2-1. 서 론

동해는 전형적인 주변해 (marginal sea) 혹은 후호상 분지 (back-arc basin)로서 판구조적으로는 태평양판과 필리핀판위에 겹쳐있는 아무리아판에 놓여있다. 동해의 지각구조는 주로 일본분지, 야마토분지, 그리고 울릉분지의 세개 심해분지에서 수행된 탄성파 굴절자료를 기초로 구명되고 있다 (Fig. 2-1) (Ludwig, 1975; Hirata et al., 1987). 현재로서는 이들 분지가 함몰작용과 관련된 back-arc spreading과 복잡한 판운동에 의해 형성되었음을 시사한다 (Chough and Barg, 1987). 탄성파 굴절자료의 분석결과, 일본분지는 지각구조가 전형적인 해양성 (oceanic) 으로 인지되었다 (Ludwig, 1975). 야마토분지는 상부 및 하부지각의 탄성파속도분포가 해양성이지만 지각의 두께가 해양성지각에 비해 두배정도인 것으로 밝혀졌다 (Fig. 2-2) (Chung, 1991).

이들 두개에 비해 울릉분지의 지각구조는 그 중요성에도 불구하고 거의 연구된 바 없다. 울릉분지는 Korea Plateau와, 동해에서 가장 많은 구조운동을 받은 한반도의 남동쪽과 접해있으으로 이의 지각구조는 동해의 형성 및 진화를 이해하는 데에 매우 중요할 것으로 생각된다.

울릉분지의 지각구조를 조사하기 위해 한국해양연구소 (KORDI)와 러시아 과학아카데미 소속의 Instititue of Marine Geology and Geophysics (IMG&G)가 공동연구로서 1991년 8월과 1993년 3월 두 차례에 걸쳐 해저면 지진계 (OBS)와 대용량의 에어건을 이용하여 탄성파 굴절법 탐사를 수행하였다. 이 연구에서는 울릉분지에서 모호면까지의 지각층서를 정확히 알고자 연속적으로 에어

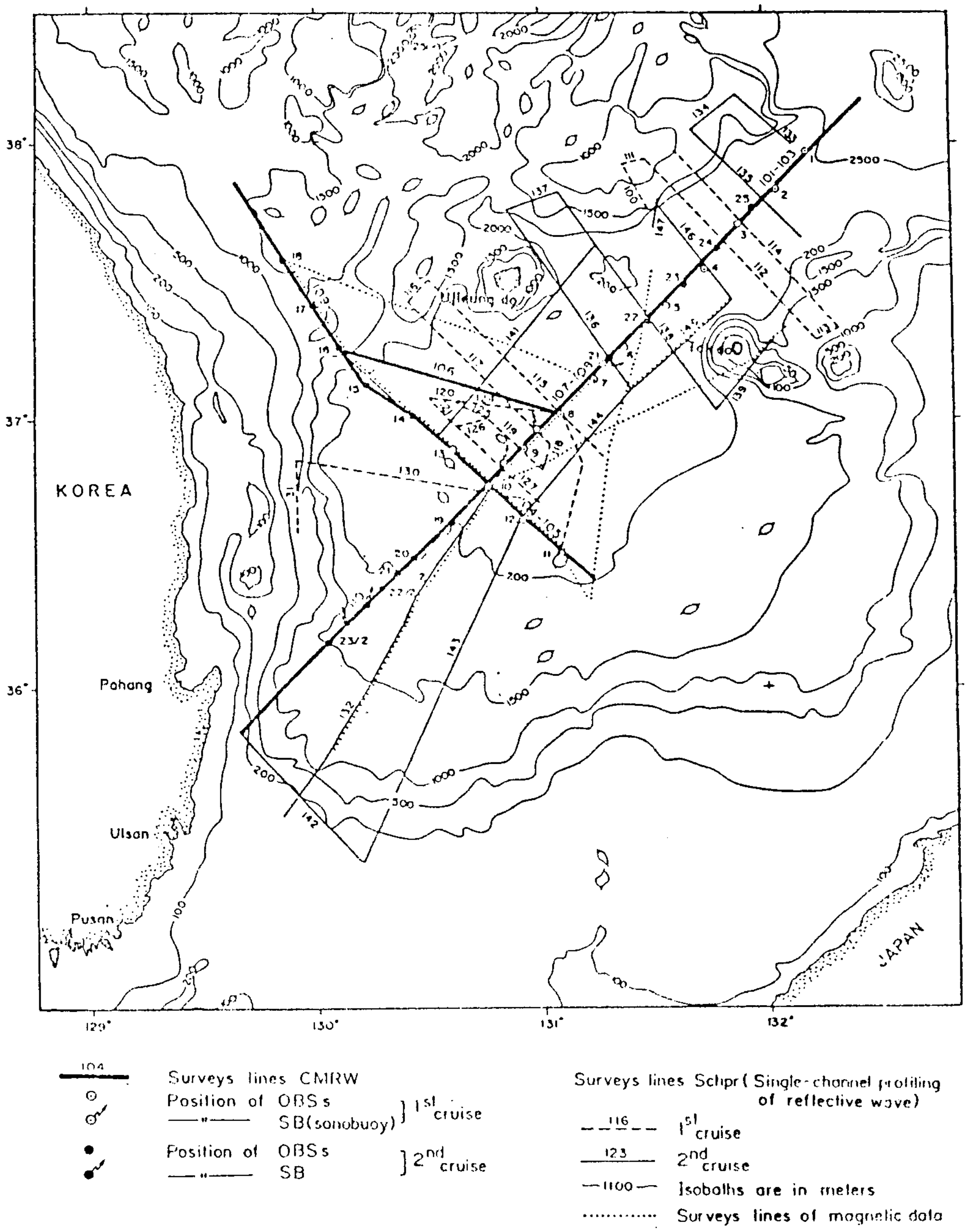


Fig.2-1. Configuration and setting of the experiment.

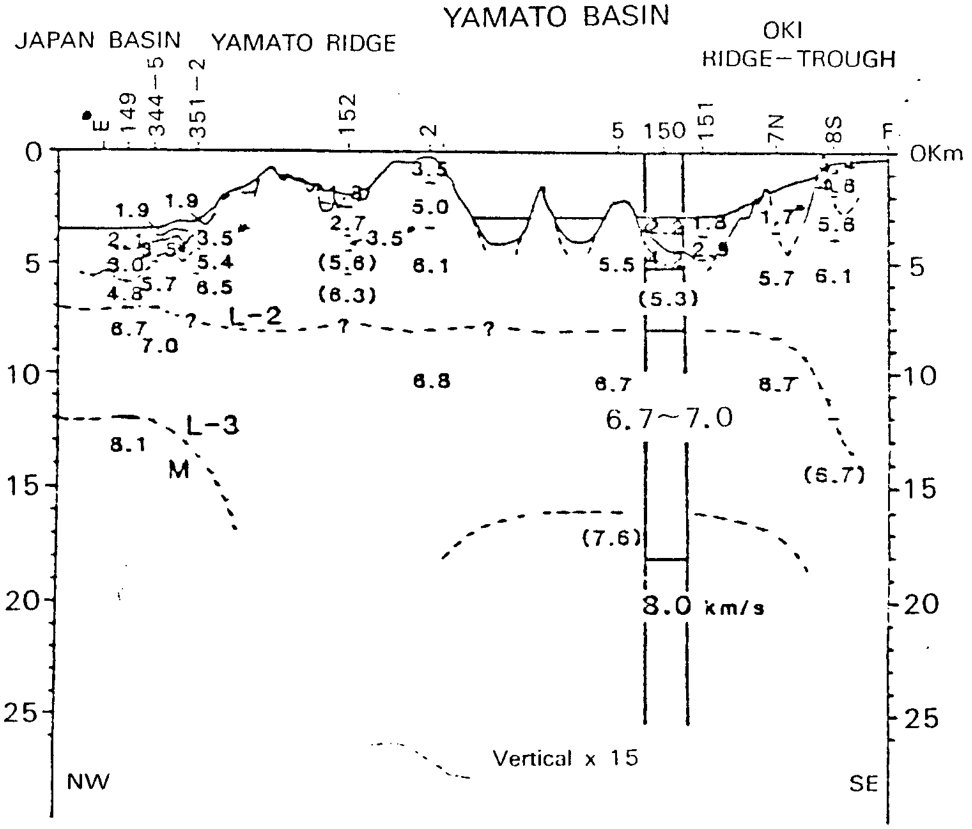


Fig.2-2. The schematic structure section of the East Sea from the Japan to the Yamato Basin (from Hirata et al., 1987).

로 에어 건을 발파함으로써 얻는 OBS자료를 분석하는 기술을 개발하는 데에 중점을 두었다. 현재로서는 1991년에 획득한 OBS자료를 대부분 분석하였으며 1993년에 획득한 OBS자료는 기본처리중에 있다. 따라서 여기에서는 지금까지 분석한 1991년의 한국-러시아 공동연구의 결과를 제시하고자 한다.

2-2. 울릉분지에서의 OBS 탐사

해저면 지진계를 이용한 탄성파탐사는 한국해양연구소(KORDI)와 러시아 과학아카데미소속의 Institute of Marine Geology and Geophysics (IMG&G) 간의 공동연구로서 1991년에 수행되었다. 조사선은 러시아 측의 R/V Gagarinsky와 R/V Morskoy Geofizik 를 사용하였다. 탄성파 조사측선은 울릉분지의 퇴적방향(Line A)과 그 직교방향(Line B)으로 설정하였으며 각각의 길이는 대략 300 및 200 km 이다(Fig.2-1). 현장탐사시 R/V Morskoy Geofizik 가 정해진 측선을 따라 약 20 km간격으로 설정된 28개 지점에 OBS를 해저면까지 내리면 R/V Gagarinsky가 측선을 따라 60 리터용량의 에어 건을 2분 간격 (750 m)으로 발파하면서 움직여 약 200km 구간까지의 multi-offset 자료를 얻을 수 있었다. 에어 건은 주파수 8 - 20 Hz 의 탄성파를 발생시키며 심부 지각을 조사하기에 알맞도록 제작되었다.

에어 건을 발파함과 동시에 14 Kjoule의 용량을 갖는 스파커파원을 이용하여 연속적인 지층단면 탐사 (continuous profiling)를 수행하였다. 이때 얻은 지층단면자료로부터 울릉분지 상부의 퇴적물분포를 파악하여 OBS자료해석시 이용하였다.

2-3. OBS 자료 해석

2-3-1. OBS 기록 단면

OBS를 회수한 후 자기 테이프에 아날로그방식으로 기록된 탄성파 트레이스들을 digitize한 후 기록단면을 만들었다. 원래 기록은 여러 성분의 잡음을 포함하고 있으므로 신호 대 잡음비를 높이기 위해 6 - 12.5 Hz주파수 대역을 갖는 FIR (finite impulse response) 필터를 설계하여 전체 자료에 적용하였다. 일차적인 기록단면을 만들 때에는 X(송수신수평거리)/20 km의 인수를 곱하여 거리에 따른 진폭 감쇠를 보정하였다. 최종 기록단면은 recuction velocity 7.0 km/sec로 linear moveout하여 작성하였는데 이때 사용한 7.0 km/sec는 해양성 하부지각(layer 3)의 대표적인 탄성파 속도로 알려져 있다. 따라서 최종 기록단면에서 수평방향으로 나타나는 신호들은 해양성 하부지각의 존재와 특성을 바로 지시해준다고 볼 수 있다. 기록단면의 송.수신거리에서 "+" 및 "-" 표시는 각각 북쪽 및 남쪽 방향을 지시한다. 이 보고서에서는 OBS 기록단면에서 볼 수 있는 탄성파 굴절신호로부터 확인된 외견 속도 5.2 - 5.8 km/sec의 층을 상부지각 (layer 2)으로, 그리고 외견속도 6.5 km/sec의 층을 하부지각 (layer 3)으로 분류하였다.

기록단면의 해석을 위해 먼저 하부에서 굴절된 후 처음으로 해저면에 도달한 탄성파 (first arrival)를 추적하여 대체적인 지각구조와 타성파속도를 파악하였다. 다음에 2-D ray tracing (Cerveny and Psencik, 1983)기법을 이용하여 대략적으로 구한 지각구조와 탄성파 속도분포를 수정시켜 원래의 탄성파 기록단면에 가장 적합한 지각모델을 구성하였다.

OBS-1 (측선 A). 이 기록단면(Fig. 2-3)은 측선 A 의 북쪽 끝에 위치하는 OBS-1로부터 남쪽으로 70km 이상의 범위를 갖는다. 약 15 km범위 내에서 탄성파 자료는 성공적으로 기록되지 못하였지만 이 이후부터 일차파가 나타나는데 이들은 지각내에서 굴절된 후

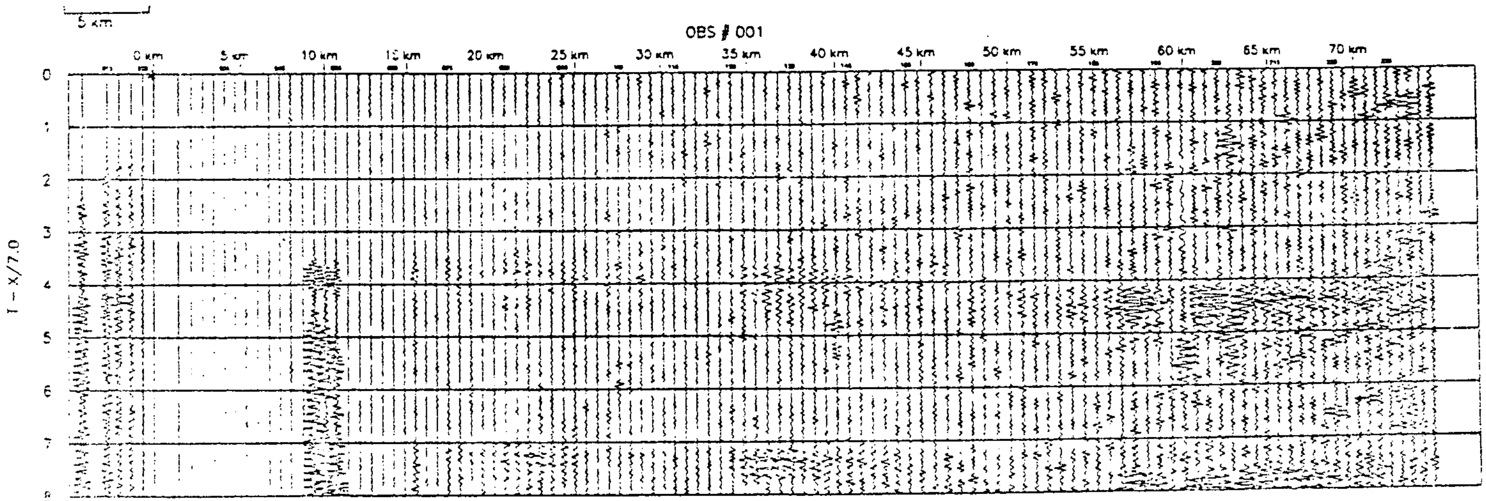


Fig.2-3. Record section of OBS-1.

해저면에 도달하는 탄성파이다. 약 35 - 45 km 범위에서 강한 신호를 관찰할 수 있는데 외견속도가 약 6.5 km/sec이므로 해양지각을 구성하는 하부지각의 탄성파 속도와 일치한다. 모호면에서 초임계 반사된 파형 (PmP)은 약 55km 이후부터 아주 강하게 나타나지만 상부맨틀층내에서 굴절된 파형 (Pn)은 관측할 수 없다. 일반적인 해양성지각의 경우 강한 Moho triplication이 약 25 - 35km 범위부터 발생하는 것에 비추어 볼 때 울릉분지의 경우 약 55km 이후부터 보이는 Moho triplication은 하부지각 (layer 3)이 일반적인 해양성 지각보다 훨씬 더 두꺼운 것을 지시한다.

OBS-4 (측선 A). 이 자료는 울릉분지의 북쪽에 위치한 OBS-4에서 북쪽으로 얻은 것으로 (Fig. 2-4) Line A상에서 얻은 대부분의 기록은 서로 유사한 바 울릉분지 하부의 지각이 대체적으로 수평방향으로 균일한 층서를 가진 것으로 짐작할 수 있다. 기록단면은 북동방향으로 70 km 이상의 연장을 가지며 확연히 구분되는 탄성파 신호는 추적하기에 용이하다. 4 - 11 km 구간의 탄성파신호는 약 5 km/sec 이상의 외견속도를 가지는데 이것은 상부지각에서 굴절된 파로 해석할 수 있다. 13 km 부근부터 50 -60 km 구간사이에서 상관성이 우수한 신호는 7 km/sec보다 조금 낮은 속도를 갖는데 이것은 하부지각에서 굴절되어 온 탄성파이다. 이 자료의 가장 중요한 특징은 55 km구간부터 Moho triplication을 분명히 볼 수 있다는 것으로 위의 OBS-1 기록과 마찬가지로 울릉분지의 하부지각은 정상적인 해양성 지각보다 매우 두꺼운 것을 알 수 있다.

OBS-6 (측선 A). 울릉분지의 중심부에서 얻은 OBS-6의 기록단면 (Fig. 2-5)은 두 개의 상이한 속도를 갖는 탄성파 신호를 보이는데 약 13 km 범위를 경계로 구분된다. 이것은 위의 OBS-4의 기록단면에서 약 11 km 범위에서 상부 및 하부지각의 경계가 나타남을 고려할 때 울릉분지의 중앙부에서 상부지각이 북쪽보다 다소 두꺼움을 시사한다. 하지만 40 km 범위 이후로는 일차 신호들을 추적하기가 힘들며 50 km 범위 이후의 신호는 PmP로 해석된다.

OBS-7 (측선 A). OBS-7은 OBS-6에서 남쪽으로 40 km 떨

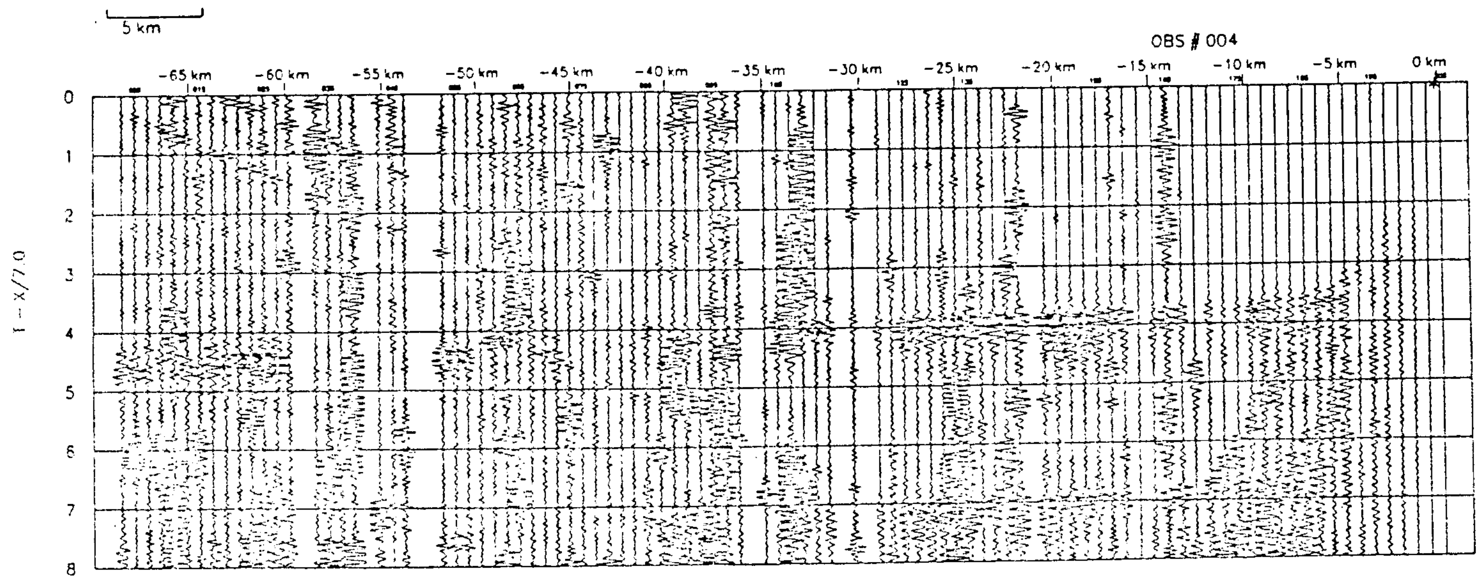


Fig.2-4. Record section of OBS-4.

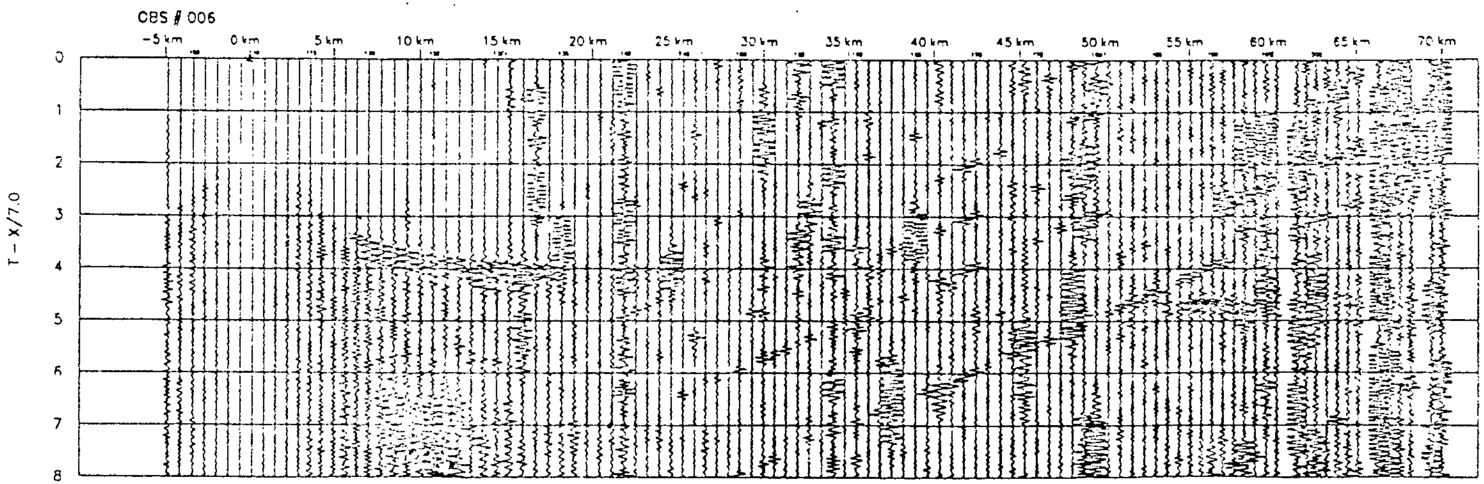


Fig.2-5. Record section of OBS-6.

어져서 위치하는데 OBS-6과 대동소이한 특성을 보여주므로 (Fig. 2-6) 울릉분지의 중앙부가 큰 변화가 없는 지각구조를 가진다고 볼 수 있다.

OBS-12 (측선 B). 이 기록은 분지의 중앙부에서 측선 B를 따라 얻은 것으로 기록방향은 북서쪽이다 (Fig. 2-7). 자료는 layer 2 및 3에서 굴절된 탄성파와 모호면에서 반사된 p파 (PmP) 신호를 분명히 보여준다. 지각의 층서 및 탄성파 속도는 OBS-4와 거의 비슷하지만 상부지각이 다소 더 두꺼우며 하부지각은 약 8 km 의 두께를 갖는 것으로 해석된다. 모호면은 평균 16 km깊이에 평탄하게 존재하며 상부 맨틀에서 굴절된 신호 (Pn)는 분명히 보이지 않는다.

OBS-13 (측선 B). OBS-13은 OBS-12의 40 km 북쪽에 위치하며 이 기록단면은 (Fig. 2-8) OBS-12 기록단면과 반대방향이므로 측선 B의 지각구조를 정확히 얻을 수 있다. 앞의 OBS-12의 기록과 거의 같은 특징은 지각구조가 측선 B를 따라 수평방향으로 균질함을 제시한다. 즉 북서-남동 방향으로 울릉분지의 중앙부는 매우 평탄한 지각 층서와 모호 불연속 반사면을 갖는다고 볼 수 있다.

2-3-2. OBS 기록의 해석

OBS 기록단면의 외견 속도와 주시로부터 일차적인 지질모델을 추측한 후 2-D ray-tracing 기법 (Cerveny and Psencik, 1983)을 이용하여 조사측선 하부의 지각모델을 유추하였다. 이론적으로 계산한 탄성파도달시간은 여기에서 예시하는 각 기록단면에서 별표(*)로 표시하였다. 현재로서 최종 지각모델은 결정하지 못하였으나 tau-p 영역에서의 파형분석 등을 통해 보다 정확한 결과를 제시할 수 있을 것이다.

울릉분지의 북쪽 및 중앙부를 대표하는 OBS-4 및 OBS-12 하부의 지각구조는 Fig. 2-9 과 Fig. 2-10에 예시되어 있다. 여기에서 울릉분지의 지각은 매우 분명하게 최상부의 퇴적층, 상부지각, 그리고

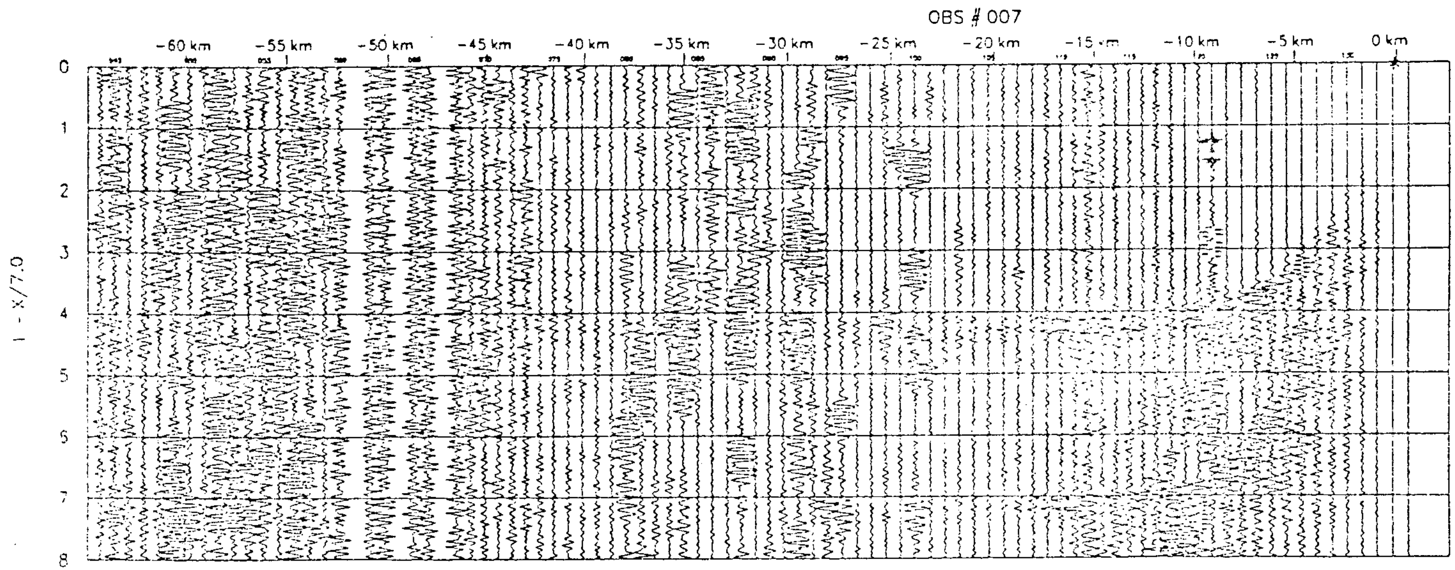


Fig.2-6. Record section of OBS-21.

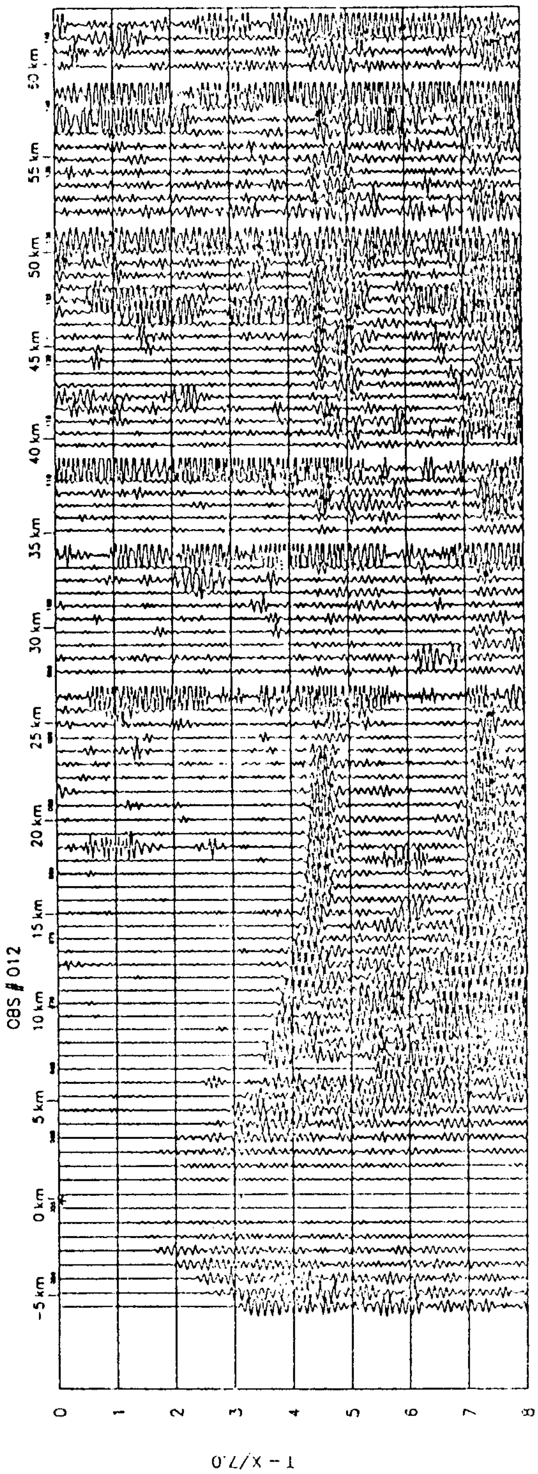


Fig.2-7. Record section of OBS-12.

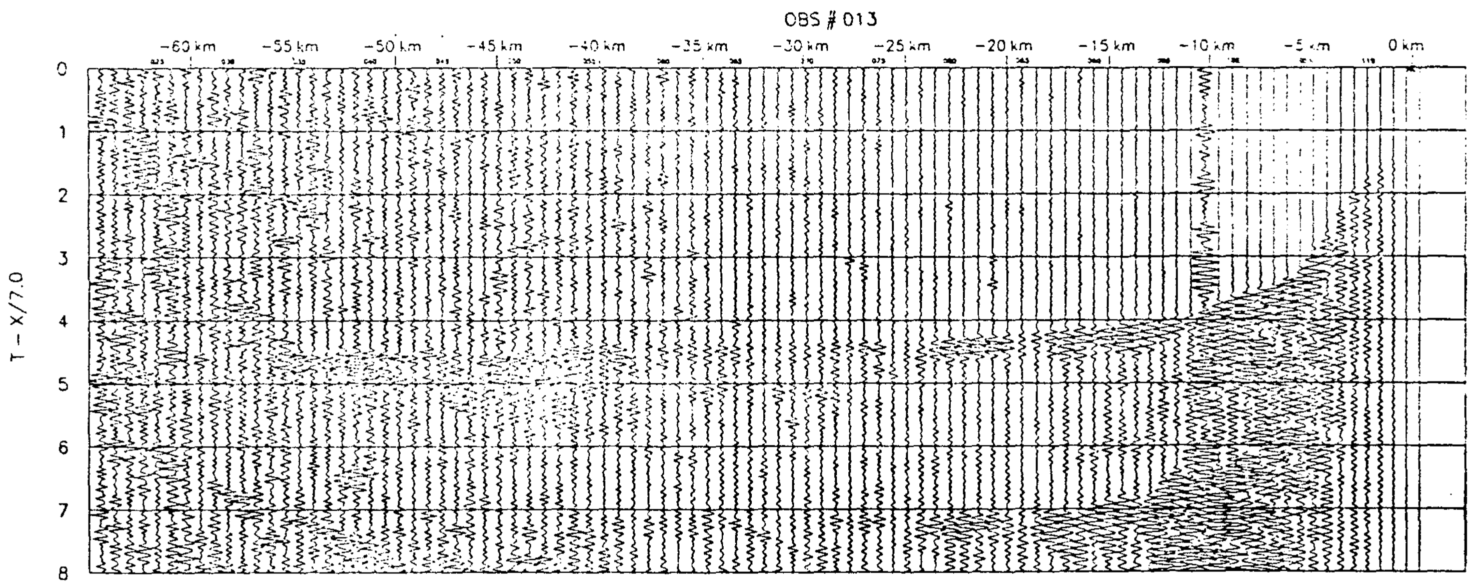


Fig.2-8. Record section of OBS-13.

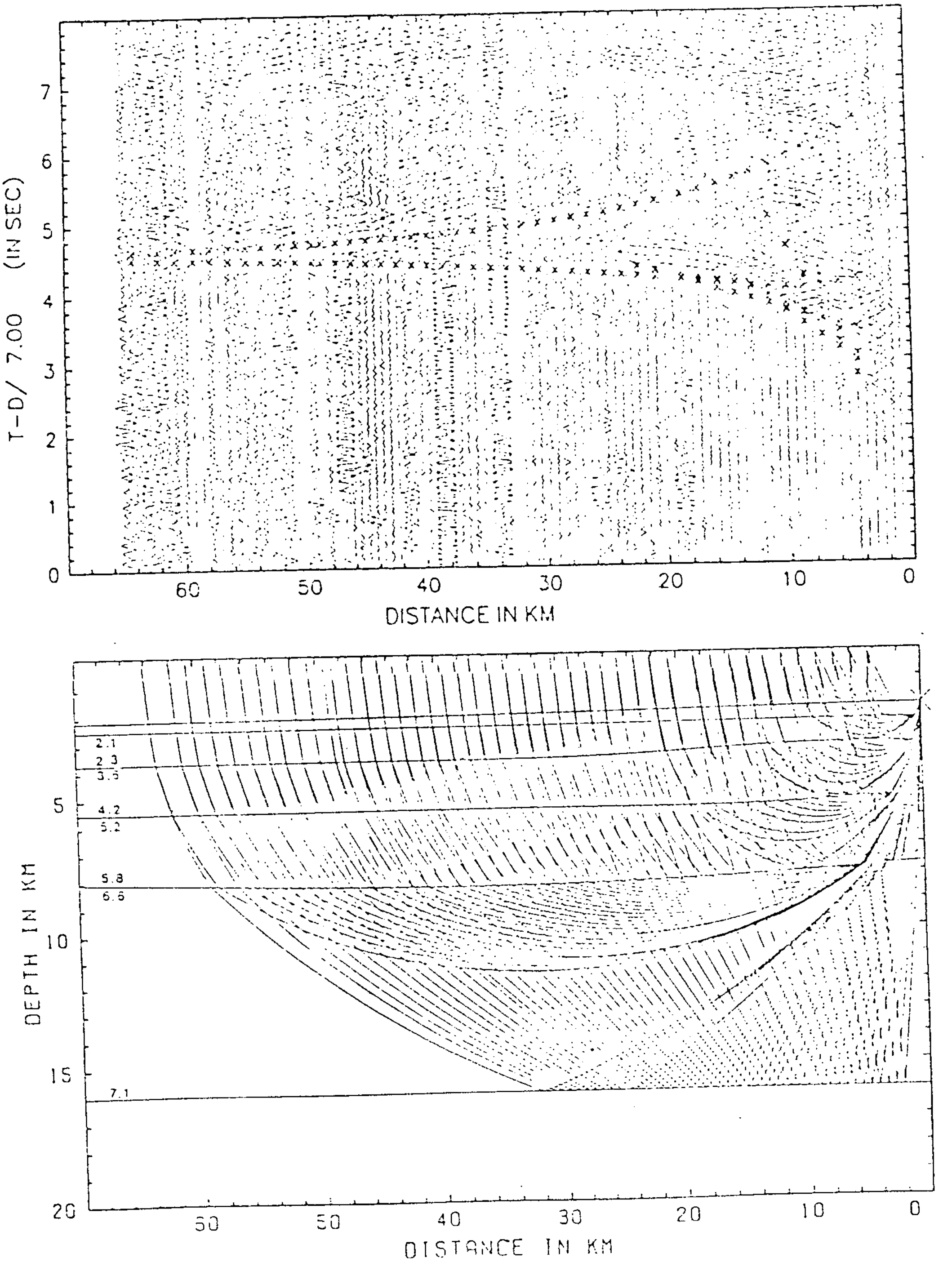
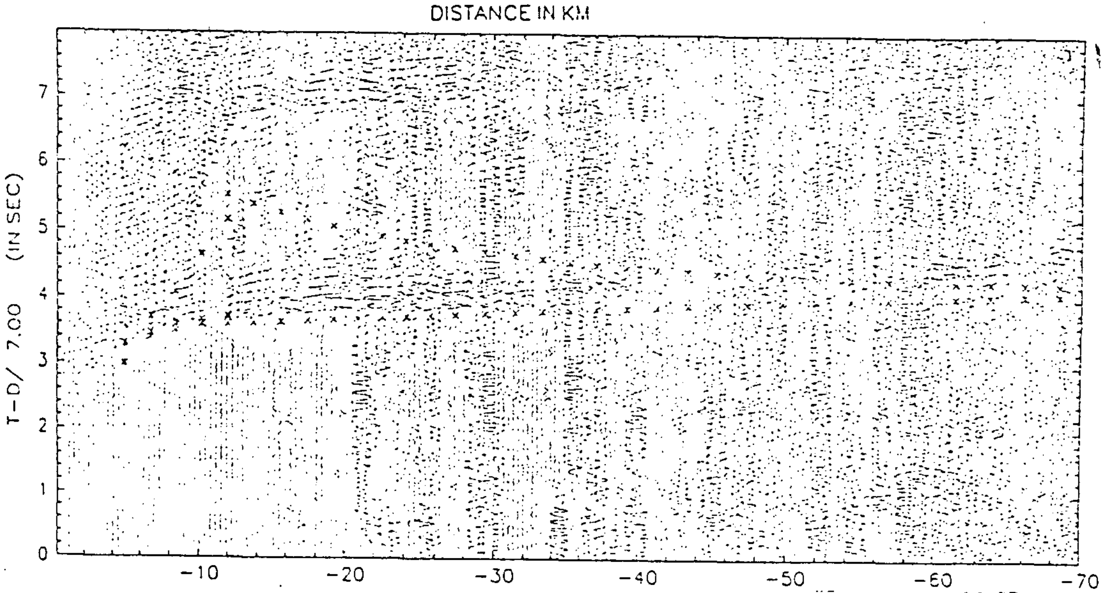


Fig. 2-9 (a) Record section of OBS-4 with calculated travel times denoted by stars(*), (b) Ray diagram for the constructed seismic cross section.



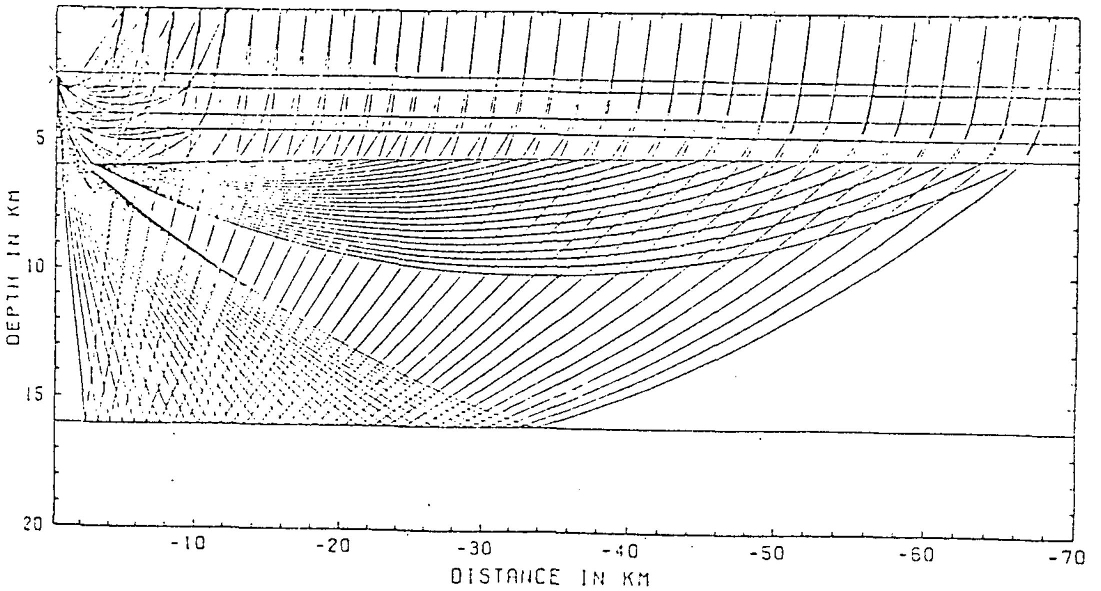


Fig. 2-10 (a) Record section of OBS-12 with calculated travel times senoted by srars(*), (b) Ray diagram for the constructed seismic cross section.

하부지각으로 구성되어 있음을 볼 수 있다. 이들은 해양성 지각의 경우 각각 layer 1, 2, 그리고 3에 상응한다. 이중 퇴적층은 3개의 세부층들로 구성되며 (layer 1-1, 1-2, 그리고 1-3) 특히 분지 중앙부 및 남쪽으로 두꺼워지는 최하부의 퇴적층 (layer 1-3)은 탄성파 속도가 3.6 - 4.2 km/sec로서 매우 높다. 이것은 울릉분지의 경우 퇴적층과 상부지각과의 경계부에 해당하는 음향기반(acoustic basement)의 광물학적 조성과 비교하여 해석할 필요가 있으나 차후 연구에서 구명하고자 한다. 상부지각은 그 속도 및 두께에서 전형적인 해양지각의 특성을 가지며 남쪽으로 오면서 다소 두꺼워진다. 하부지각의 경우 속도분포는 해양지각과 일치하지만 두께는 8 - 10 km 로서 해양지각에 비해 거의 두배에 이른다. 또한 전체적으로 모호면은 약 16 km의 깊이에서 매우 평탄하게 발달되어 있다.

2-4. 울릉분지의 지각구조 (토의 및 결론)

전체 OBS 자료로부터 구한 Line A와 B의 지각구조는 각각 Fig. 2-11에 예시되어 있다. 대부분의 OBS기록에서 상부 및 하부지각에서 굴절된 신호를 분명히 볼 수 있었으나 일부 자료에서는 PmP가 불분명하여 되어 모호면을 정확히 구할 수 없었다.

울릉분지의 전지역은 최대 4 km 이상의 퇴적물로 덮혀있으며 지각은 수평방향으로 발달해 있다. 울릉분지는 뚜렷하게 상부 및 하부지각으로 구성되어 있으며 상부지각의 경우 탄성파 속도와 두께에서 정상적인 해양지각의 층서특성을 보인다. 하지만 하부지각은 북쪽이 약 10 km 두께를 가지며 중앙부에서 조금 얇아져서 8 km의 두께를 가지는데 이것은 해양지각의 약 두배나 된다.해양성 하부지각이 이렇게 두꺼운 것은 해저확장이 매우 강한 압축력에 의해 급격히 정지되면서 맨틀하부의 용융물질들이 수직방향으로 관입되어 형성되기 때문으로 추정하고 있다 (Hirata et al., 1989). 울릉분지에서 모호면은 약 16 km 깊이에서 매우 평탄하게 존재한다.

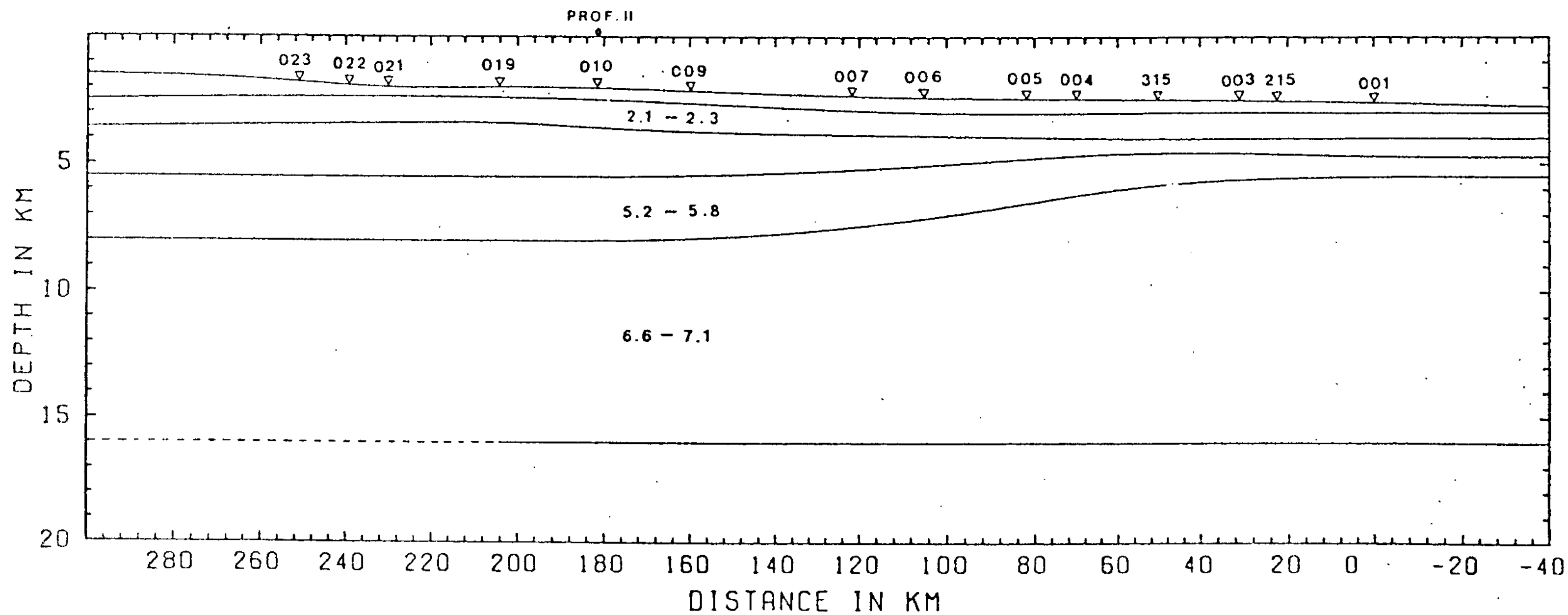


Fig.2-11. Velocity-depth structure for Profile II based on preliminary interpretation.

전체적인 층서가 단순한 퇴적층, 상부지각, 그리고 하부지각으로 구성되어 있다는 점과, 속도 분포에서 전형적인 해양지각과 일치한다. 특히 상부지각은 두께에서도 해양지각이라고 볼 수 있다. 울릉분지의 경우 하부지각이 해양지각의 layer 3 보다 두배정도 깊다는 점이 해양지각으로 정의하는 데에 어려움을 다소 주므로 주변해에서 지각의 형성 및 진화, 그리고 layer 3의 특성을 좀 더 명확히 파악하여야 할 것이다.

제 3 장

울릉분지 북서 일원에서의 해상중력탐사

제 3 장 울릉분지 북서일원에서의 해상중력 탐사

3-1. 서론

해양조사선 온누리호의 취항과 함께 양질의 해상중력 관측이 이루어 지고 있다. 중력이상은, 주로, 지구내부의 밀도구조를 반영하며, 이에 따라 태평양이나 내서양 등 대양저의 해산, 해구, 해령, 해분와 같은 대규모 지질학적 해저구조를 밝힘으로서 plate tectonics 의 확립에 크게 기여하였다는 것은 주지의 사실이다.

본 연구는, 해상에서의 중력 관측자료를 이용하여, 장기적으로, 한반도 주변해역에 있어서의 고정밀도의 중력이상, 지오이드의 기복을 결정하고, 이와 더불어 지구내부의 밀도구조, plate tectonics, geodynamics 등에 관련된 지질학적, 지구물리학적 연구 수행을 위한 포석을 마련하는 데 목적이 있다. 또한, 중력측정의 정밀도 향상에 의하여 국지지역의 3차원 밀도구조에 대한 보다 정확한 정보의 추출이 가능하다는 점에서 해저 가스, 석유자원의 탐사등 산업적 측면에서 활용할 수 있는 연구를 구체화 시키고 있다.

국내의 경우에 있어서는 있어서는 그동안 해상중력계가 전무한 상태에 있었기 때문에 해상중력측정이 전혀 이루어지지 않았으며 이에 따라 활용 가능한 관측자료가 극히 제한적이었다는 점에서 해상중력을 이용하는 연구가 비교적 소홀하였다고 아니할 수 없다. 최근에 이르러 한국해양연구소에서 종합조사선의 취항과 국내 최초의 해상중력계 도입 설치로 해상중력관측이 가능해졌으며 이에 따라 현장에서의 해상중력 관측자료의 수집에서부터, 중력이상의 정밀 결정을 위한 각종의 보정 기술을 확립시켜 나가고 있다.

한편, 중력 관측자료의 빈곤에서 오는 문제점을 해결하기 위하여, 외국의 연구기관 등에서 이미 공개한 자료를 수집하여 이들의 정밀도를 평가하고, 이를 이용하여 한반도 주변해역에 있어서의 고정밀도의 중력이상을 편집하거나 해면고도계 인공위성에서 관측한 해면고도 관측자료를 중

력이상으로 변환하여 활용하는 방안을 마련하고 있다.

3-2. 선상중력관측

중력관측자료의 정밀도가 육상의 경우 0.01 mgal 에 이르고 있을 만큼 양질 임에 반하여, 해상의 경우 통상 10 mgal 정도로서 여기에는 다음과 같은 전형적인 오차 요인들이 복합적으로 작용하고 있다. 즉, (1) 육상중력 기준점과의 중력 결합의 불일치, (2) 중력계의 기계적 특성에 기인하는 sensor calibration, drift 보정의 불확실성, (3) 측지기준계 채용의 불일치, (4) 관측선박의 부정확한 위치결정에 기인하는 Eotvos 보정의 부정확성 등이라고 하겠다.

이중에서, (1)-(3)은 중력계의 특성 및 중력관측을 수행한 당시의 정보를 바탕으로 검토되어야 할 부분이며 이들은 (4)와 달리 계통적 오차 특성을 갖는다. 그런데 해상중력 관측오차의 대부분은 (3)에 기인한다고 하여도 과언이 아니다. 최근에 이르러 GPS 등이 실용화 되어 비교적 정확한 선위결정이 이루어 지고 있으나 1980년대 후반까지만 하여도 해상에서의 위치결정은 NNSS 또는 LORAN-C 등에 의존할 수 밖에 없었다는 데에 그 원인이 있다고 하겠다.

온누리호에 탑재된 해상중력계는 zero-length spring과 복원스프링, 질량추 및 지렛대 역할을 하는 빔으로 이루어져 있는 전형적인 불안정형 중력계로 측정범위는 120,000 mgal 이다. 측정범위 0 - 10,000 mgal 사이에서의 수평, 수직 가속도의 변화 실험에서도, 최대 오차가 0.25 mgal 이내에 이르는 매우 우수한 성능을 지닌 것으로 알려져 있다. 그러나, 현장에서 관측한 자료에는 각종의 오차가 포함되어 있을 뿐만 아니라 실제 연구에 필요한 물리량은 중력이상이라는 점에서 실험실내에서의 후처리가 요구된다. 매번의 연구항해에 있어 일관성 있는 고정밀도의 해상중력을 얻기 위한 자료처리와 관련하여 상기 내용을 구분해서 기술하면 다음과 같다.

3-2-1. 측지기준계의 채용 - IGSN71계 및 GRS67 정규중력

전세계 각 지역의 중력치는 특정 지점에서의 중력 절대치, 즉, 절대중력을 기준으로 하는 국제중력기준망을 근거로 하여 상대측정하여 결정하고 있다. 본 연구에서 수행하는 해상중력 관측치는 종래의 포츠담 기준계를 대신하여 새로이 제정된 IGNS71 (International Gravity Standardization Net 1971) 을 기준으로 삼기로 한다.

지구타원체의 중력을 나타내는 이론식을 정규중력식 (nomal gravity formula) 이라고 한다. IGSN71계의 정규중력식, 정식으로는 GRS67 (Geodetic Reference System 1967) 이라고 하는 측지기준망을 근거로 하는 정규중력식은 다음과 같다.

$$\gamma_{67} = 978031.85\,(1 + 0.005278895 \sin^2\psi + 0.000023462 \sin^4\psi)$$

위 근사식은 정규중력의 엄밀해를 0.004 mgal 정도의 정밀도로 근사한다.

한편, 1979년 측지기준계에 약간의 변경이 있었고, 이에 따라 새로이 개정된 정규중력식을 1980년 기준계 정규중력식이라고 부르고 있다. 그러나 상기의 1967년 식과 1980년 식과의 차이는 미세할 뿐만 아니라, 이제야 정착한 IGSN71계를 대체하여 얻을 만한 이득이 별로 없다는 점에서 현재에 있어서도 1967년 정규중력식이 광범위하게 채용되고 있다.

3-2-2. 육상 중력기점과의 중력결합

L&R 중력계는 상대중력을 측정하는 중력계로서, 관측자료는 각 측점간의 상대적인 중력값의 차이를 나타낼 뿐이다. 따라서, 절대중력치를 이미 알고 있는 지점, 즉, 중력기준점과의 중력결합에 의한 관측치의 전이작업이 필요하다. 이를 위하여, 부산대학교 구내의 2등 수준점 (35도 13분 52초 N, 129도 04분 57초 E) 에서의 중력값으로부터, 조사선 온누리호가 주로 기항하는 진해부두 인근 3 지점의 중력값을 결정하였다. 전이작업은

육상용 중력계인 L&R gravimeter G-905 로서 왕복 측정하는 방식을 택하고 중력계의 기계적인 drift 와 지구조석 보정을 실시하였다. 전이작업의 결과로 얻어진 각 지점의 중력값은 다음과 같다 (남상헌, 윤호일; 1993).

	위 치		중 력	추정오차
	위 도	경 도	mgal	mgal
1	35 07 42.9	128 41 50.8	979770.79	0.02
2	35 07 42.4	128 41 49.8	979770.76	0.03
3	35 07 50.1	128 42 01.3	979770.91	0.03

또한, 육상의 중력기점과 해상중력계와의 고도차이를 감안하는 보정을 실시하여, 선박 관측 중력의 기준값을 결정하였다. 상기의 결과는 금후 실시할 예정에 있는 중력기점에서의 정밀 중력결정의 예비단계였음을 밝혀두는 바이다. 실제로 국내의 경우 국립지리원이 주관하여 측지측량 및 중력기점의 설정 등을 수행하고 있다는 점에서 동 기관과 협조할 필요가 있다.

3-2-3. Sensor Calibration 과 drift 보정

온누리호 탑재 L&R 선상중력계의 특징은 항진중에 연속 측정이 가능하고, 중력센서, 수평안정판 (stablized platform), 연직자이로 (Vertical gyroscope) 등 모든 장치를 SEASYS 라는 시스템 S/W 에 의하여 자동적으로 제어하고 있다는 점에서 매우 안정적이라고 하겠다. 또, 선박의 위치, 선속, 방위각 등과 측심 자료 등이 동시에 기록되어 실시간에서의 중력 profile 의 개요를 알 수 있는 잇점이 있다. 그러나, 항해 및 기항 일수 또는 입출항에 따른 중력계의 기계적 특성이 미세하게나마 변할 수 있다는 점에서 매번의 연구항해에 있어 이를 고려하는 calibration 의 필요성이 생긴다.

따라서 보다 정밀한 중력측정을 위하여 최소한 출항 2일전 부터 중력계를 작동시키고 있으며 여기서 얻어진 관측치로 부터 예비단계의 sensor calibration, drift 보정에 대한 정보를 추출하고 있다. 이와 더불어, 지구조석의 영향 및 입항 후의 관측자료를 추가로 이용하여 보다 정확한 calibration 과 drift 보정이 이루어지도록 하고 있다.

Sensor calibration 의 경우에는 zero meter reading의 값이 3-2-2에서 구한 육상기점에서의 중력치와 일치하도록 spring tension, skewness를 조절하는 단계를 말하며, drift 보정이란 중력값의 선형적인 증가 또는 감소를 제거하기 위한 처리라고 하겠다. 따라서, sensor calibration 은 기계적으로, drift 보정은 통계적 방법에 의하여 별도로 수행할 수 있다고 하겠으나 본 연구에서는 이들을 묶어서 통계 처리하는 방법을 채택하였다. 즉, 육상 기점에서의 중력치와 선상 관측치와의 차이를 d_0, d_1, ..., d_2, 관측시간의 차이를 t_0, t_1, ..., t_n, 선상중력계의 meter reading 값을 m_0, m_1, ..., m_n 이라 한다면 이로부터 다음과 같은 행렬식을 만들 수 있다.

$$[\, d_0 \quad d_1 \quad d_2 \ldots d_n \,]^t = \begin{pmatrix} 1 & t_0 & m_0 \\ 1 & t_1 & m_1 \\ 1 & t_2 & m_2 \\ & & \\ 1 & t_n & m_n \end{pmatrix} [\, A \quad B \quad C \,]^t$$

위식에서 미지수 A 는 관측치의 bias 보정량, B 는 drift rate (mgal/hour), C 는 scale factor 로서, n 개의 관측치로 구성되는 연립방정식을 만족하는 이들의 최적치를 구하는 방식을 채택하고 있다. 따라서, 최종적인 중력관측치 g_m' 은 다음과 같다.

$$g_m' = g_m + A + B\,t + C\,m$$

여기서 g_m 은 선상에서의 중력관측치를 나타낸다.

3-2-4. Eotvos correction

항해하는 선박에는 Coriolis force가 작용한다. 따라서, 항해하는 선박에서 관측한 중력은 정지하고 있는 상태에서 관측한 값과 비교하여 커거나 작아지며, 선박의 위치 및 속도벡타의 함수로 나타난다. 이를 Eotvos 효과라 하며 정지한 상태에서 관측한 값으로 전환시키는 처리를 Eotvos 보정이라고 한다.

적도상을 항해하는 선박에서 관측한 자료를 1 mgal 의 정밀도로 보정을 하기 위해서는 선박의 속력이 1knot, 방위각이 0.1도 이내의 정밀도로 결정되어야 한다. 다행히 온누리호의 항법장치가 GPS 를 충분히 활용할 수 있다는 점에서 비교적 정확한 선위 결정이 이루어지고 있다. 그러나 cycle slip 등 GPS 운용상의 문제에 의하여 항해 전기간에 걸쳐 균질의 위치자료의 획득이 보장되는 것은 아니다. 이러한 점에서, 경우에 따라서는, GPS 뿐만 아니라 LORAN-C, NNSS 등에 의한 선위자료를 병행처리하는 방식을 채택하고 있다.

3-2-5. 교차점 오차의 보정

상기의 3-2-1로부터 3-2-4까지의 처리 과정에 의하여 관측자료가 실제 해면상에서의 중력으로 전환된다. 그런데 해상중력자료의 처리에 있어 통상적으로 사용하고 있는 부가적인 방법으로서 이른바 교차점오차를 최소로 하는 처리를 하고 있다. 즉, 항적의 교점에서의 관측치가 같아야 한다는 개념을 이용하는 것으로, 특히, Eotvos 보정의 부정확성을 보강하는 데에 아주 유효하다고 할 수 있다. 뿐만 아니라, 중력결합 또는 정규중력식 채용의 불일치 등 다른 연구기관에서 입수한 자료들에 내재한 상이한 문제점들을 일거에 해소시키는 데에도 효율적이다.

3-3. 중력이상

중력치는 관측지점의 위치, 고도 그리고 측정시각에 따라 다르게 나타난다. 이들 측점간의 명확히 다른 관측환경의 차이를 보정함으로써 다른 관측점에서 측정한 값과 비교할 수 있도록 하는 처리를 중력보정이라 하며, 각종의 보정 후에 남은 중력관측치의 잔차를 중력이상 (gravity anomaly) 이라고 한다. 중력이상은 free-air, 단순부게, 그리고 지형보정을 고려한 완전부게이상 등으로 구분하여 사용한다.

3-3-1. Free-air 이상

중력관측치로부터 정규중력을 제거하고 또한 대기의 질량에 의한 인력과 관측점의 고도차에 의한 영향을 보정한 나머지를 free-air 이상이라고 한다. 해상에서는 관측이 해수면상에서 이루어지므로 고도차에 의한 영향을 고려할 필요가 없다. 따라서, free-air 이상 Δg_{fa} 는,

$$\Delta g_{fa} = g_m - \gamma(\psi) + 0.87$$

로 표현된다. 여기서 g_m은 중력관측치, γ는 GRS67 기준계의 정규중력치이고, ψ 는 측점의 위도, 마지막 항의 0.87은 대기의 질량에 의한 인력을 나타낸다.

3-3-2. 단순부게이상

해상에 있어서의 부게이상은 관측점 즉 해수면과 해저면 사이를 해수 대신에 수심에 대응하는 두께를 갖는 무한평판의 가상적인 암석으로 대체하였을 경우에 나타나는 중력이상을 말한다. 해수의 밀도를 ρ_1, 암석

의 밀도를 ρ_2 라 한다면 해상에서의 단순부게이상 (simple Bouguer anomaly) Δg_{ba} 은,

$$\Delta g_{ba} = g_m - \gamma(\psi) + 0.87 + 2\pi G(\rho_2 - \rho_1)h$$

로 표현된다. 여기서 G는 만유인력상수, h는 수심 (meter) 을 나타낸다. 일반적으로는, 해수 (1.03 g/cm^3) 를 지각암석으로 대체하는 처리를 채용하고 있으며, 지각암석의 평균밀도를 2.67 g/cm^3 로 한다면 위식은,

$$\Delta g_{ba} = g_m - \gamma(\psi) + 0.87 + 0.06876\,h$$

로 된다.

해상에서의 중력이상을 부게이상으로 나타내는 데는 장단점이 있다. Free-air 이상이 해수의 인력, 즉, 해저지형을 강하게 반영하기 때문에 해저의 밀도구조를 추정하기에는 부게이상으로 표현하는 것이 편리하다. 그러나, 해수층을 지각의 구성물질 (일반적으로 2.67 g/cm^3) 이라고 하는 특정의 밀도를 가진 지층으로 가정하는 데에서 기인하는 구조해석의 불확실성을 배재할 수 없기 때문이다. 특히, 대륙붕 등 저밀도 퇴적물이 두텁게 분포하는 지역에서의 구조해석에는 단순부게이상이 적절치 않으며 퇴적층의 두께, 밀도 등을 고려하는 처리가 필요하다.

3-3-3. 부게이상

상기의 단순부게이상에다 정밀성을 더하기 위해서는, 3차원적인 해저지형을 고려하는 보정량의 계산이 필요하다. 최근까지만 하여도 단순부게이상과 부게이상을 구분치 않고 사용하여 온 것이 사실이다. 그 이유로서는, 해저지형의 수치데이타가 충분치 않다는 점 이외에도 측점 (해면)과 해저면의 거리가 비교적 멀다는 점에서 주변지형에 의한 영향이 크지

않기 때문이다.

경우에 따라서는, 해저지형을 2차원적으로 근사하여 보정하는 경우도 많다. 이것은 위에서 언급한 이유 외에도, 해상에서의 중력조사가 직선적인 측선을 따라 행하는 것이 보통이며 해저지형을 보정함에 있어 필요한 수심자료가 중력측정과 병행하여 이루어지기 때문이다. 그러나, 대륙붕이나 해저산 등 수심이 얕은 지역, 또는 해저지형이 크게 변하는 해역에서는 3차원적 보정의 필요성이 대두된다.

3 차원적 지형보정의 방법으로서, 본 연구에서는, 해저지형을 수평면적이 5'x5' 이고 높이가 h (즉, 5'x5 구역의 평균수심) 인 수직격자로 근사하여, 관측점으로 부터 반경 약 100 km 이내에 분포하는 지형에 의한 인력을 보정하는 방식을 택하고 있다. 수직각주에 의한 인력의 계산식은 다음과 같다 (Fig.3-1).

$$\delta g = \sum_{i,j,k=1,2} (-1)^{i+j+k-1} f(x_i, y_j, z_k)$$

여기서,

$$f(x,y,z) = G\Delta\rho \left[x \ln \frac{y+r}{(x^2+z^2)^{1/2}} + y \ln \frac{x+r}{(y^2+z^2)^{1/2}} + z \arctan \frac{zr}{xy} \right]$$

이며, $r=(x^2+y^2+z^2)^{1/2}$ 로서 계산점으로 부터 격자점 까지의 거리를 나타낸다.

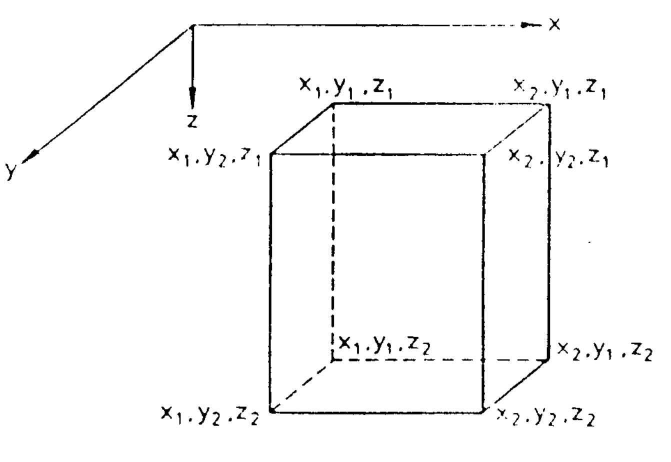


Fig. 3-1 Rectangular parallelepiped

3-4. 온누리 해상중력측정

3-4-1. 해상측정 및 중력보정

1993년 5월 동해 울릉해분 북부일원에서 조사선 온누리호와 L&R 사의 해상중력계를 이용한 해상중력자료와 다중빔 측심기를 이용한 2 차원 해저지형자료가 획득되었다. 조사지역은 동경 129° 30′ 에서 131° , 북위 37° 에서 37° 40′ 해역이며 경도 2-3° 간격의 남북간 측선을 따라 조사되었다(Fig.3-2).

해상중력측정의 절대중력환산을 위해서 진해부두의 육상중력기점을 출항 입항시 중복 측정하였으며 해상에서의 중력측정자료는 선위 및 선수방위각등의 조사선 기동자료와 함께 해양측정자료 종합 logging 시스템인 MDM(Marine Data Management) 시스템을 통해서 웍 스테이션에 0.5초간격으로 자동기록하였다. 상대중력치인 해상중력치는 육상의 중력기점의 중력치를 이용하여 절대중력으로 환산되고 조석보정 및 계기보정이 실시되었다. 계기보정은 동일 지점에서 출항전 6 시간, 입항후 26시간 연속측정한 두 그룹의 중력자료군을 통계 자료처리하여 얻은 계수로써 -0.0198935 mgal/hour(남상헌 윤호일, 1993)를 이용하였으며 조석보정은 Longman (1959)에 의한 기조력 계산식을 이용하여 산출 보정하였다. 후리에어 중력이상치는 GRS67 표준중력치 보정을 통해서 산출하였으며(Fig.3-3), 2.67g/cm3의 밀도를 적용한 단순부게 중력이상치(Fig.3-4)가 산출되었다. 부게이상 산출을 위한 밀도선정을 위하여 두 개측선에 대하여 밀도변화에 따른 부게이상치를 계산한후 해저지형과 대비한 결과 2.67 g/cm^{3}일 때 지형의 영향이 최소로 반영되었다(Figs.5,6).

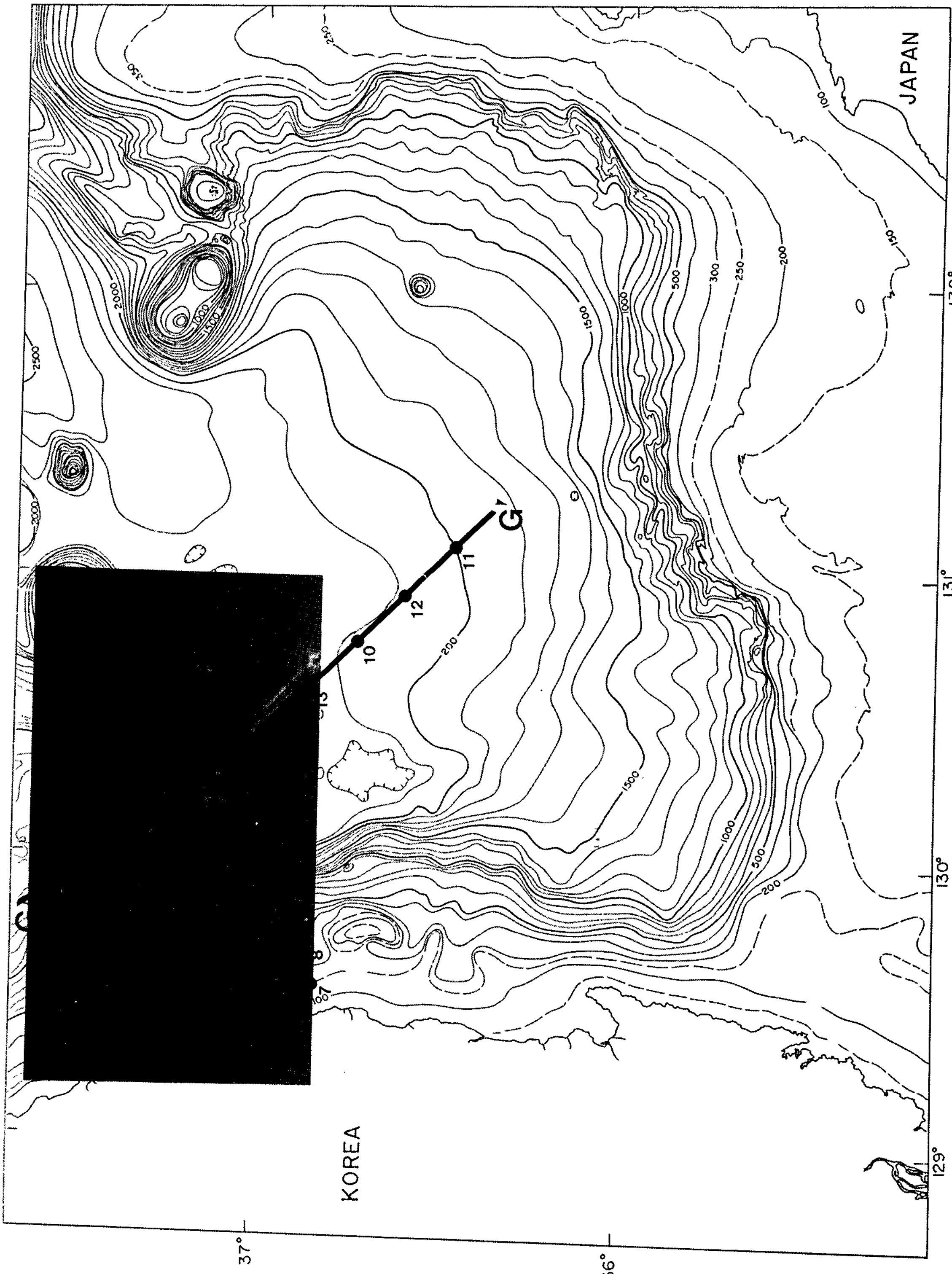


Fig.3-2. The study area. OBS refraction method was done along the sections F-F′ and G-G′

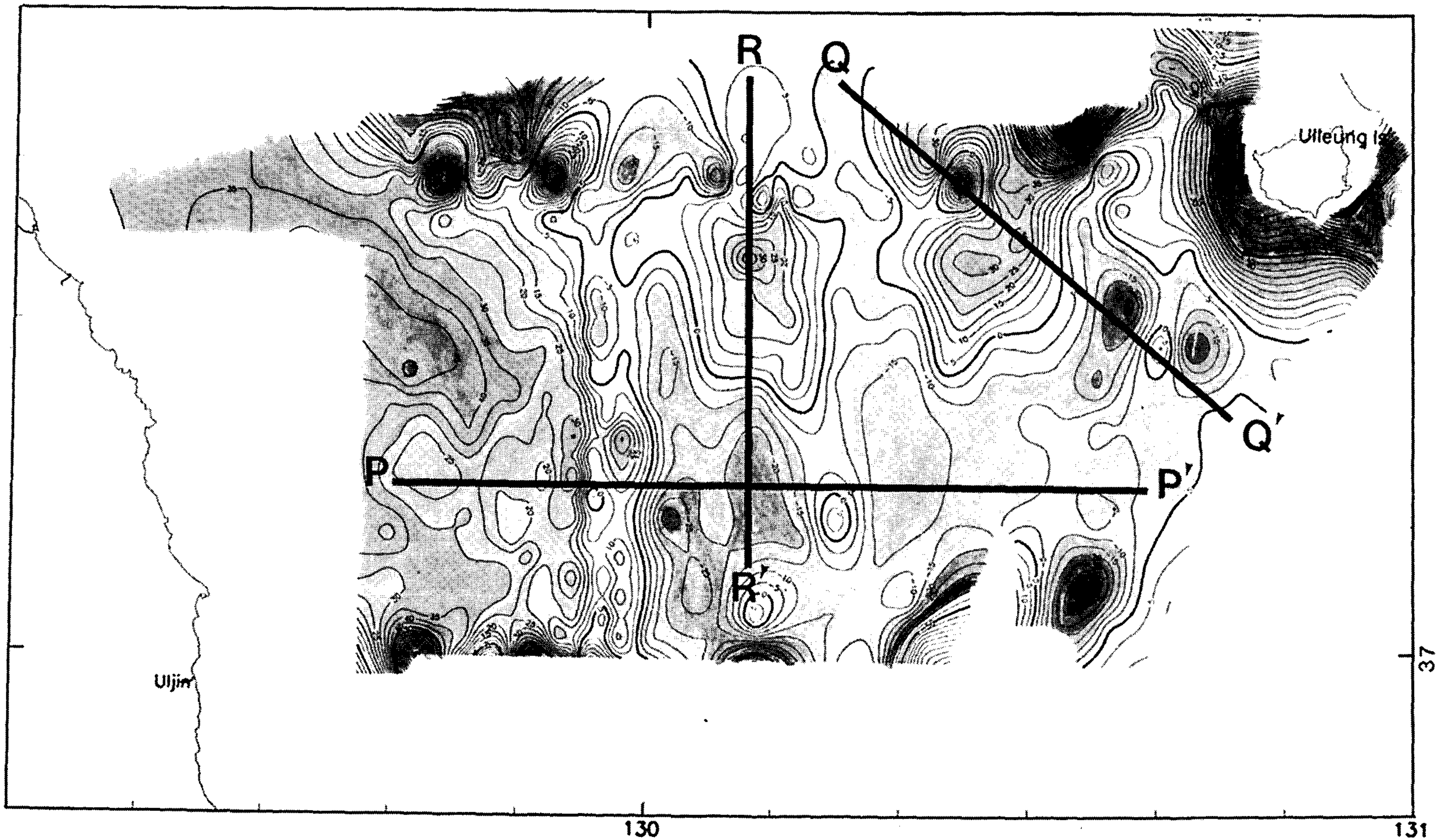


Fig.3-3. Free-air gravity anomaly map. Contour interval is 5 mgal.

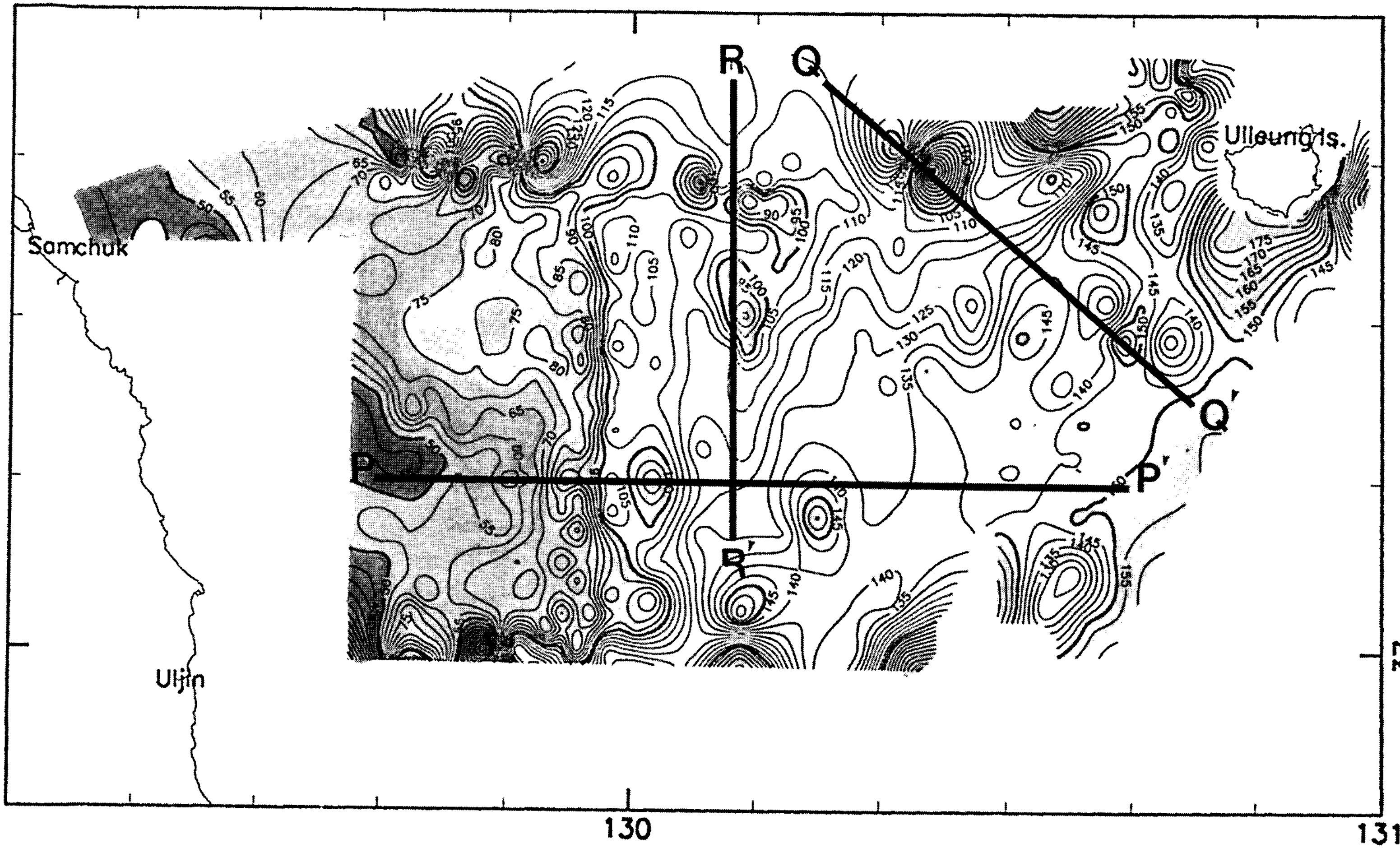


Fig.3-4. Simple Bouguer gravity anomaly map. Contour interval is 5 mgal.

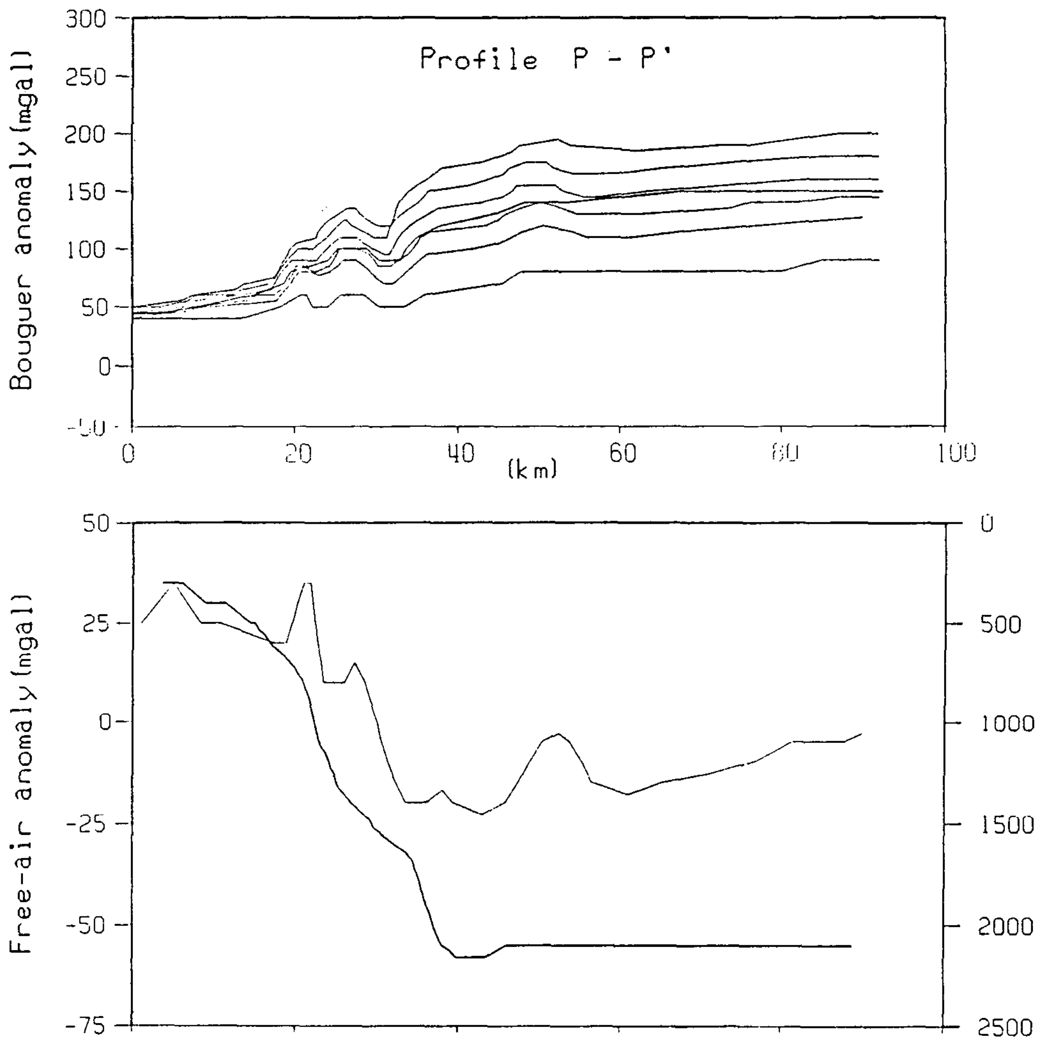


Fig.3-5. Bouguer anomaly profiles according to density variation for the profile P-P′.

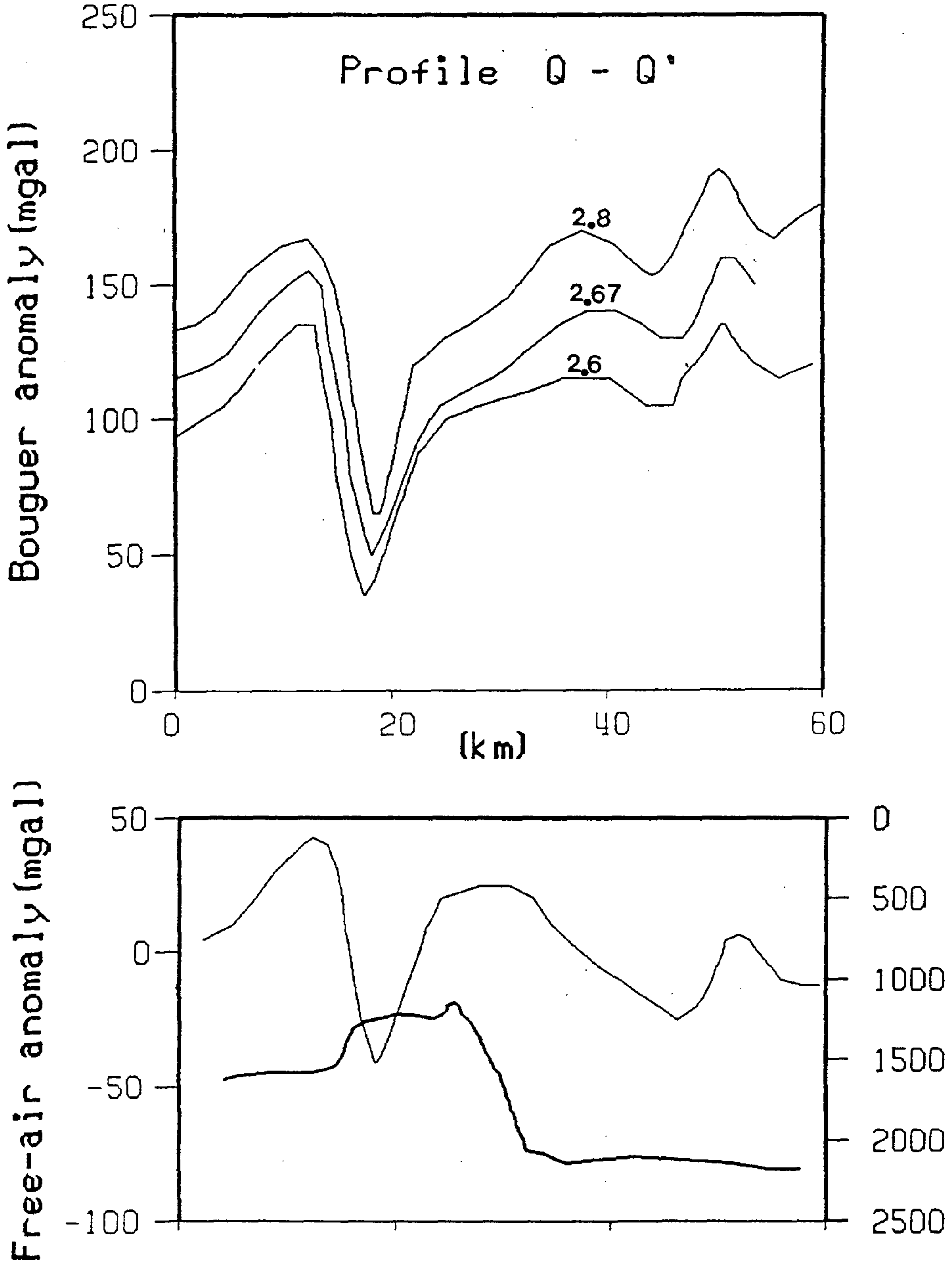


Fig.3-6. Bouguer anomaly profiles according to density variation for the profile Q-Q'.

3-5. 중력이상 해석 및 토의

해저지형은 다중빔 2 차원 정밀 측심기에 의해서 상세하게 밝혀졌다. 한국대륙쪽에서는 분지쪽으로 급한 사면이 형성되어 있고 북쪽의 분지 가장자리를 따라서는 울릉도의 해저와 함께 두 개의 규모가 비교적 큰 해저산 및 해저곡의 지형이 복잡한 양상으로 놓여 있으며 해분저는 비교적 평탄하게 이루어져 있다(Fig.3-7).

후리에어이상은 해저지형의 영향에 잘 부합된다. 특히 울릉도 주변 및 그 서쪽에 위치하고 있는 두 개의 해저산상의 후리에어 이상은 그 분포형태가 매우 유사하다. 또한 한반도쪽의 대륙사면상에서는 남북방향으로 발달하고 있는 지형상 선구조에 부합되는 중력이상분포가 잘 나타나고 있다(Fig.3-3). 반면에 분지 남부나 울릉도 서쪽 두 개의 해저산 중력이상분포에서 지형상 큰 변화가 없음에도 그 주변에서 고밀도의 음의 저이상대가 나타나는 데 이는 그 지역이 주변에 비해 지하지층밀도가 현격히 다르다는 것을 시사한다. 부게이상은 동해연안의 40mgal에서 해양쪽으로 점차 증가하는 경향을 나타내면서 분지 중심부에서 160mgal까지 높아진다(Fig.3-4). 이는 대륙에서 해양쪽으로 지각의 두께가 얇아지면서 지각평형에 의해 고밀도 맨틀의 심도가 낮아지기 때문이며 OBS 탐사 결과 본 역에서의 맨틀상부까지의 심도는 심도는 서쪽의 약 35 km에서 해양쪽으로 약 16 km까지 얕아진다(Fig.3-8). 부게이상에서 동경 130 상 남북방향으로 높은 구배의 뚜렷한 선형분포는 단층의 존재를 나타낸다. 이 단층은 울릉분지의 서쪽 경계를 이루는 단층으로써 탄성파 굴절법 탐사결과의 속도구조단면 G-G'상의 FZ1에 해당하는 것으로써 결과 단층의 동측이 1 km 이상 침하된 대규모 단층이다(Fig.3-8). 그보다 남쪽에서 거의 동서 방향인 측선 F-F'의 탄성파 구조단면에서도 FZ1이 연장되고 있다(Fig.3-9).

Profile Q-Q'와 Profile R-R'는 똑같이 해저산상에서의 중력이상을 나타낸것이다(Fig.6, Fig.10). R-R'에서는 free-air 이상이나 부게이상 모두 해저산의 지형을 반영하여 중앙에 높은 이상분포가 나타나고 있으나 Q-Q'에서는 지형상 높은 해저산의 정상부 북측으로 매우 급구배를 갖는 낮은 중력이상을 보이고 있다. 해저산상의 저이상분포는 정상부의 함몰구

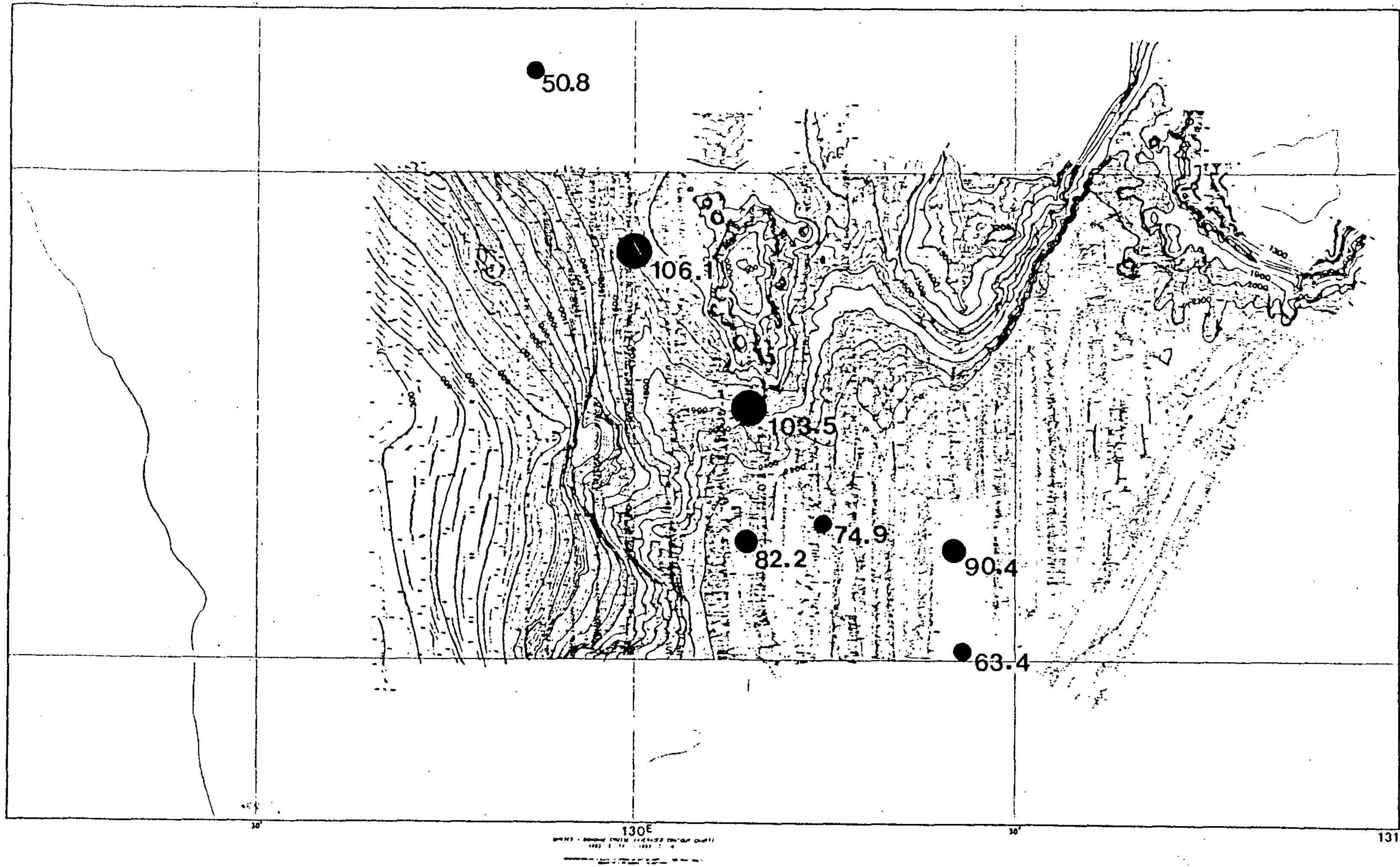


Fig.3-7. Seabed topography produced by SeaBeam 2000 muti-beam echosounder. Number is heat flow gradient in K/m $\cdot$ 10^{-3}

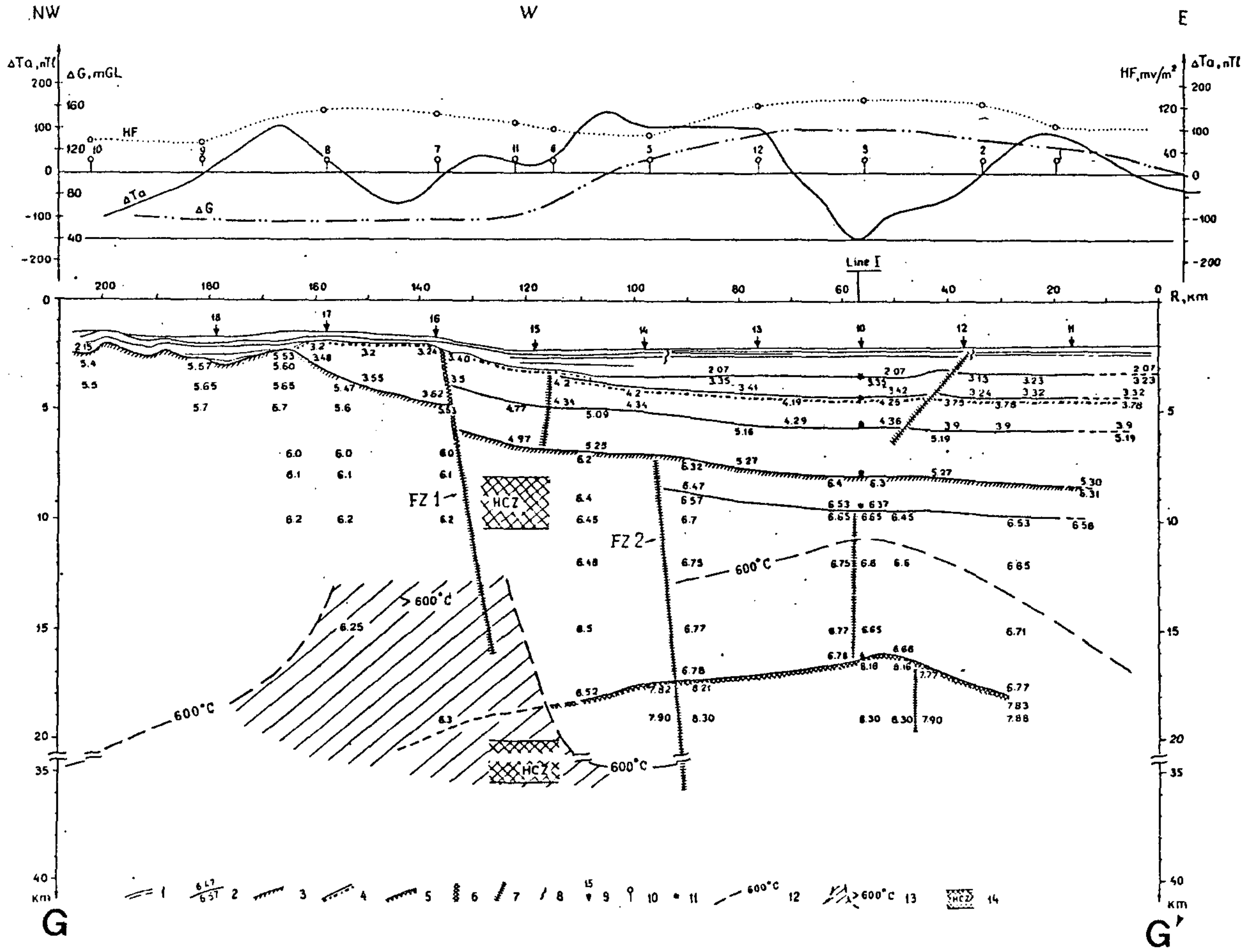


Fig.3-8. Crustal structure in terms of seismic velocities determined by refraction(OBS) or reflection method and heat flow on section G-G'.

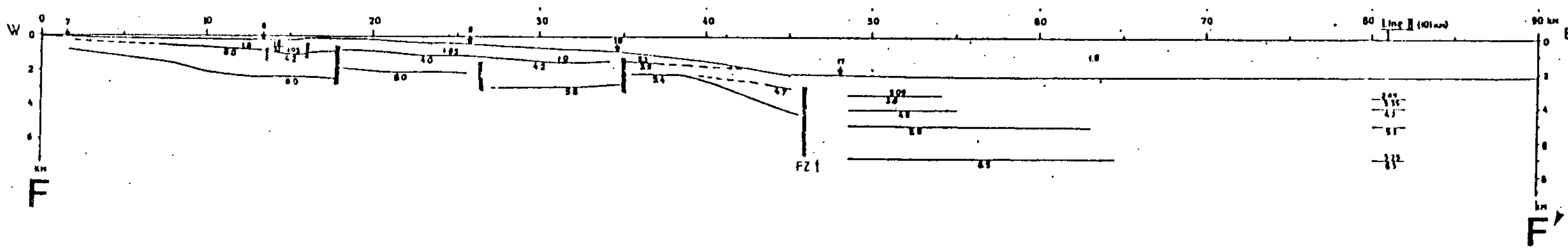


Fig.3-9. Crustal structure in terms of seismic velocities determined by refraction(OBS) or reflection method on section F-F'.

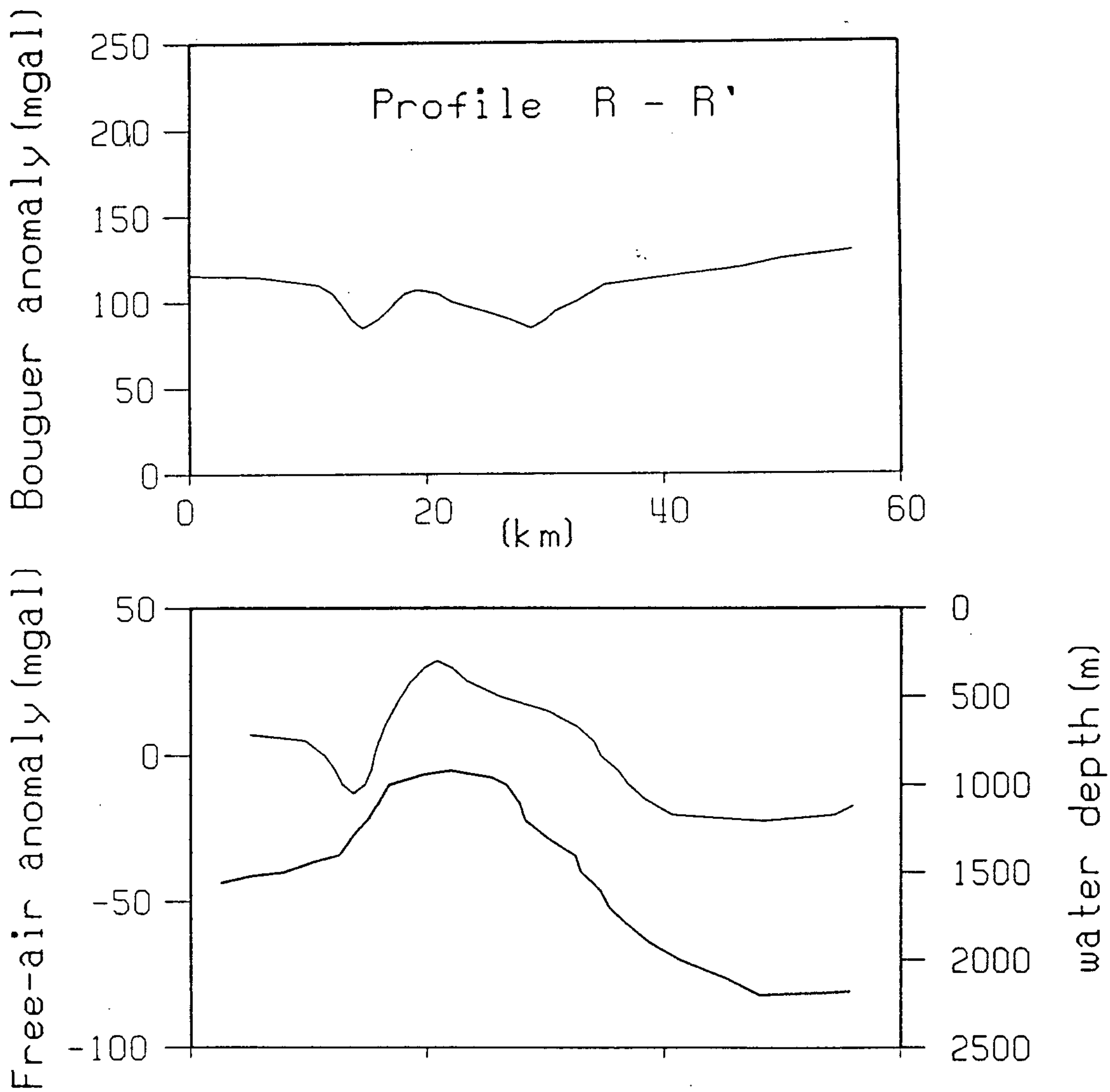


Fig.3-10. Gravity anomaly and topography on seamount(Profile R-R').

조에 밀도가 낮은 퇴적층이 충진되어 있거나 해저산 하부 맨틀이 해저산 하부 천부에 존재를 가정할 수 있다. 한편 본 역의 해저면 열류량 측정 결과 북서단에서는 낮고 해분저에서 에서 다소 높아지는 경향을 보였으나 서쪽의 해저산 측면상에서 이상적으로 높은 열류량을 나타냈다(Fig.3-3). 열류량에 의한 지하온도 분포 산출결과 600° C 등온선은 동해연안에서는 30-35km이며 분지중앙부로 가면서 얇아져서 12-14km까지 상승한다(Fig.3-9). 특히 본 연구지역 서쪽의 해저산 주변에서 높게 상승되어 있으며 이는 해저산상 부게이상 분포도 동쪽의 것에 비해 현저히 낮은 것과 비교된다. 이들은 서쪽 해저산하부에 맨틀이 천부까지 상승해 있다는 반증이고 이 해저산이 화산활동에 의해 형성된 해저산일 가능성을 시사한다.

3-6. 한국해역에서의 해상중력연구 문제점 및 방향

현재까지 한국해역에 대하여 외국의 연구기관 등으로부터 입수하여 활용 가능한 기존자료는 다음과 같다. (1) NGDC 선상중력 관측자료, (2) Altimetry satellite에 의한 해면고도 관측자료만을 이용하여 구한 NOAA의 World image 중력자료, (3) 선상중력과 해면고도를 묶어 처리하여 구한 동경대학 해양연구소 자료 등이다.

그러나 이들 자료를 활용하는 데 있어서의 문제점은, 첫째 지리적으로 일본에 가까운 해역에 한해서 산발적인 관측에 그쳤다는 점, 둘째 해면고도 자료에는 각종 오차가 복합적으로 내재하고 있을 뿐만 아니라 해면고도가 지오이드와 정확히 일치하지 않는다는 점, 셋째 한반도 주변해역, 특히, 한국 서남해와 황해에서의 자료의 신뢰도가 매우 낮다는 점등을 들 수 있다.

이러한 점에서, 상기의 기존자료와 함께 (1) 온누리호 탑재 선상중력계에 의한 해상중력 관측자료의 이용, (2) Altimetry Satellite에 의한 해면고도 관측자료처리 기술의 개발, (3) 범지구 규모의 지구중력모델 등을 활용하여 한반도 전역의 지질, 지구물리학적 연구에 충분히 활용가능한 고분해능, 고정밀도의 자료를 산출할 수 있는 방안이 필요하다.

PART I-2

부산수산대학 부문

제 4 장

독도의 지질과 암석지구화학적 특성

제 4 장 독도의 지질과 암석지구화학적 특성

4-1. 서 론

북서태평양 대륙주변부에서 일어난 신생대 판구조운동으로 한반도와 그 주변에선 활발한 화산활동이 수반되었고 일본열도와 유라시아대륙 사이에는 동해해분이 형성되었다. 울릉도, 제주도, 추가령지구대, 및 백두산 등이 잘 알려진 화산활동 지역인데 이 들의 제4기 화산암류의 특징은 알칼리질 (Lee,1982; 원종관·이문원,1984; Kim,1985; Won et al,1986; Won & Lee, 1988)로 소위 "환동해(일본해) 알칼리암구"를 이룬다. 이들 알칼리 계열 화산암류들의 기원은 섭입되는 태평양판위의 상부맨틀이 부분용융되어 생성된 알칼리 현무암질 마그마인 것으로 해석되고 있다 (Kuno, 1959, 1966, & 1968; Green, 1970; Green & Ringwood, 1967; Ringwood, 1977; Gast, 1968; Yoder & Tilley, 1962; O'Hara, 1965).

독도는 울릉도와 함께 동해상에 위치하는 화산섬으로 역사적 및 지정학적인 측면에서 많은 관심을 모으고 있다. 이와 더불어 지질학적으로도 환태평양화산대 북서내륙지역에서의 제4기 화산활동의 산물이라는 점에서 이 지역에서의 조구조운동과 화성활동의 관계를 연구하는데 중요한 위치를 차지한다. 또한 동해의 형성과정과 그 이후에 일어난 변화를 논하는데 있어서도 울릉도와 더불어 주요한 연구과제가 되고있다. 오래전부터 많은 연구가 행해진 제주도 (Nakamura, 1925; Haraguchi, 1931; Lee, 1966; Matsumoto & Tsuji, 1969; Taneta et al, 1970; 원종관, 1976; Lee, 1982)나 울릉도 (Tsuboi, 1920; Harumoto, 1970; 원종관·이문원, 1984; Kim, 1985; Yun, 1986)와는 달리 독도는 최근까지 여러가지 어려움으로 거의 연구가 이루어지지 못하였었다. 최근에 김윤규 외(1987)는 독도화산암의 주성분 및 미량성분에 대한 연구를 통해 이들이 본원 알칼리현무암으로부터 분별정출된 것으로 해석하였다.

이 연구는 독도 (동도, 서도 및 주변일대의 암초들)에서의 화산암

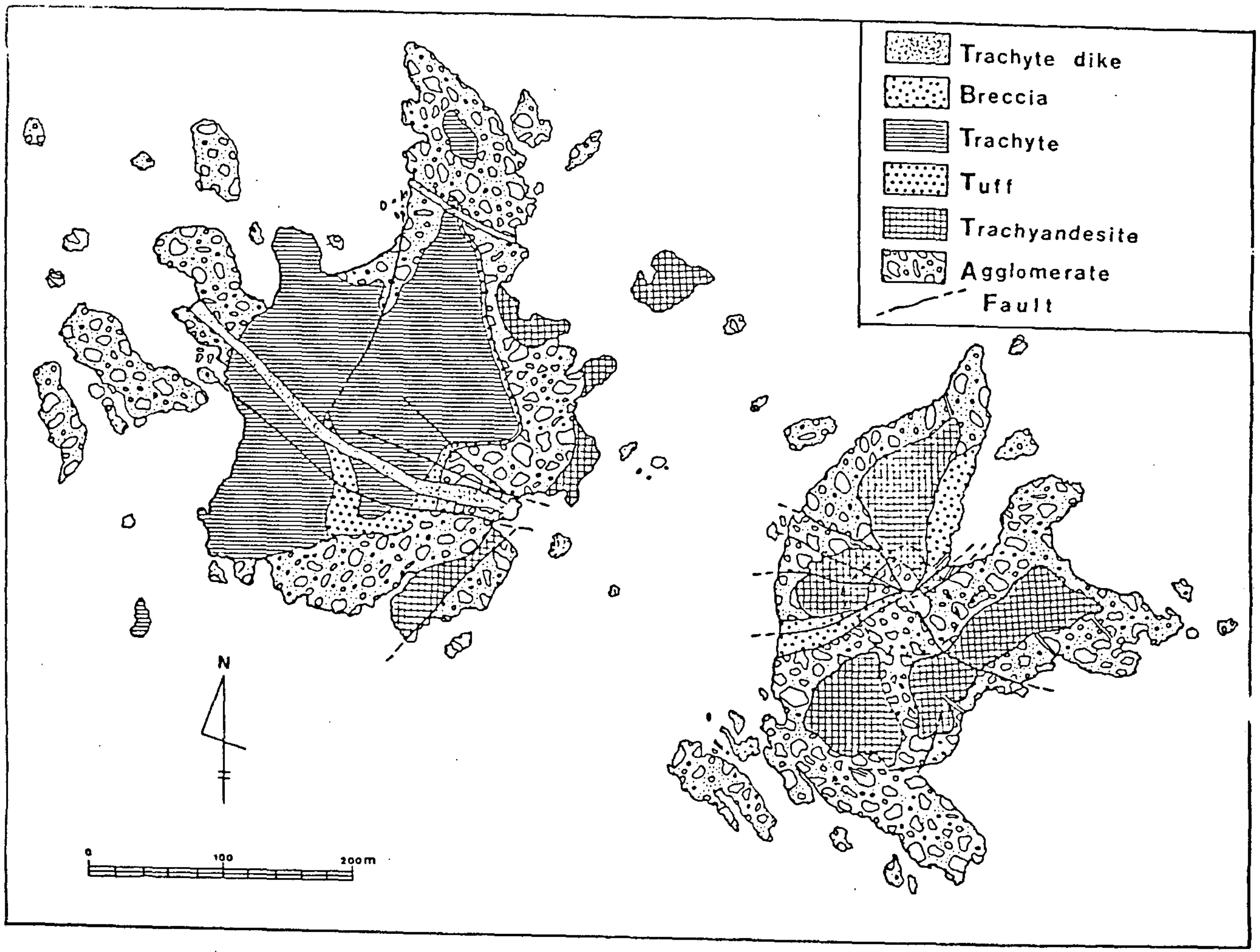


Figure 4-1. Geologic map of Tokto volcanic island.

의 분포와 층서에 대한 조사를 통해 화산활동의 단계와 그 특성을 구명하고, 각 화산암층별로 채취된 시료의 전암분석으로 주성분, 미량성분 및 희토류원소 지구화학적 특성을 조사하여 기원 마그마의 특성과 분화과정을 밝히는데 목적을 두었다.

4-2. 지질개요

독도는 동도와 서도 두개의 큰 섬과 이들 주위에 분포된 수 10개의 작은 암초들로 구성되어 있다(Plate 1a). 해수의 침식으로 지형이 급하고 험하여 접근할 수있는 지역이 상당히 제한되고 있다. 동서 양도의 하부는 크고 작은 역들을 다량 함유한 집괴암층이고 상부에 조면안산암 내지 조면암질의 용암층이 피복하고 있다 (Fig. 4-1).

동도의 경우 집괴암층의 하부는 다양한 크기의 암력들이 다량 포함된 두터운 집괴암질이며(Plate 1b), 조면안산암질 용암층 바로 아래 놓인 상부에는 얇은 층리가 발달된 응회질 층이 발달되었다(Plate 1c). 하부의 집괴암질 부분은 암회색을 띠는 층이 가장 우세하지만, 사이사이에 회백색 또는 암갈색 층이 발달되어 있어 층구분이 용이하다(Plate 2a). 상부의 응회질 부분은 역이 거의 포함되지 않은 세립질 화산회 응회암층과 함력 응회암층의 호층으로 구성되어 있으며 부분적으로 다량의 역이 포함된 집괴암층이 협재되어 있다. 응회암층들은 얇은 층리가 발달되어 있으며 층리들이 미약하지만 굴곡된 양상을 보이기도 한다. 동도의 동측 절벽을 따라 노출된 부분에선 렌즈상으로 협재된 괴상의 세립질 회백색 응회암층이 관찰된다(Plate 2b). 집괴암층은 15° 이하로 아주 완만한 경사를 보이는데 동남부에선 북서로 북서부에선 남동으로 경사되었다. 동도의 중앙부에 위치한 화구를 중심으로 남동부지역에선 급사면을 이룬 집괴암층위에 조면안산암질의 용암층이 사면을 따라 얇게 피복하고 있으며, 북쪽에선 비교적 평탄한 경계면위에 두꺼운 조면안산암층이 발달하였다. 화구를 중심으로 방사상으로 발달된 단층들에 의해 집괴암과 상위의 용암층이 함께 변위되어 있으며, 화구를 중심으로 북동 - 남서 방향으로는 각력암이 발달되었고

(Plate 2c), 곳곳에 소폭의 후기 암맥들이 관입되어 있다(Plate 2d).

서도의 남동쪽 끝 부분에 소규모의 집괴암층이 분포하며, 그 위에 서도의 동측을 따라 조면안산암질 내지 조면암질 화산암이 발달되어 있다. 이 암체는 동도의 집괴암층위에 피복된 조면안산암질 용암층과 거의 유사한 암상을 띠므로 동일 암층으로 분류하였는데 그 하위의 집괴암층과는 단층접촉을 이루고 있다. 하위의 집괴암층 역시 동도의 것과 유사한 암상을 보이지만, 조면안산암질 암층위에 놓인 두꺼운 집괴암층은 이들과는 암상에서 상당한 차이를 보인다. 이 층은 서도의 동편에선 35° 정도의 큰 각으로 서쪽으로 경사하며, 이 층과 그 위에 놓인 조면암층과의 사이에는 수 m 두께의 응회암층이 발달되어 있다(Plate 3a). 응회암층에선 그 위에 놓인 두터운 조면암의 하중에 의해 조면암체 하부에 발달된 균열면을 따라 밀려 올라간 불꽃(flame)구조가 관찰된다(Plate 3b). 서도의 북서편에선 하부는 응회암의 발달이 미약한 괴상의 집괴암층이고 위로 가면서 응회암층이 집괴암과 수 10 cm 폭으로 교호를 이루어 최상부에선 응회암층으로 이화되고 있다(Plate 3c). 동부지역에 비해 완만하게 경사한다. 응회암층 위에는 주상절리가 잘 발달된 두꺼운 조면암층이 발달하였다. 서도에서도 역시 여러 방향의 단층과 암맥들이 인지되는데, 동남동-서북서 방향으로 발달된 큰 규모의 2조의 조면암 암맥과 같은 방향으로 발달된 단층이 대표적이다(Plate 3d).

4-3. 암석기재

동도의 하부에 놓인 집괴암층은 층리는 발달되었지만 분급은 매우 불량하여, 구성 역들의 크기가 수 cm 에서 30-40 cm까지 매우 다양하다. 역들은 대체로 아원마상 내지 원마상이고, 성분도 알카리현무암에서 조면현무암, 조면안산암, 조면암 및 유리질 응회암에 이르는 여러가지 조성을 보인다. 역의 함량과 크기는 부분에 따라 상당한 변화를 보이며 흔히 역전된 점이층리를 이루고 있다(Plate 4a). 화산암력중 가장 우세한 것은 조면현무암질 역으로 보통 다공상이며 조립의 단사휘석 반정이 현저하게 발

달된 반상조직을 보인다. 단사휘석 외에 소량의 사장석이 반정으로 산출되며, 감람석 반정은 드물다. 단사휘석과 사장석은 흔히 누대구조를 보이며, 감람석은 거의 완전히 변질되어 가상(pseudomorph)으로 산출된다. 석기는 반정질(hypocrystalline)로 미립의 주상 사장석과 단사휘석, 함티탄 자철석 결정과 유리로 구성된 인터서탈(intersertal) 또는 인터스티셜(interstitial) 조직을 보인다(Plate 4b). 단사휘석 반정은 Mg/(Mg+Fe) 비가 0.70-0.79로 Mg가 풍부한 Salite에 해당된다(Fig.4-2). 사장석 반정은 An_{80-82}인 바이투나이트(Bytownite)이며, 석기부의 미립질 사장석은 An_{43-57}로 안데신(andesine)에서 라브라도라이트(labradorite)에 걸친다(Fig.4-3). 무반정질의 조면현무암력도 드물지않게 산출되며, 유백색의 조면암(Plate 4c), 황토색의 유리질 응회암, 그리고 드물게는 반려암 및 섬장암질의 심성암 암력도 산출된다. 반려암은 입상조직을 보이며, 휘석과 사장석, 흑운모, 티탄철석, 각섬석 등으로 구성되어 있는데(Plate 4d), 반려암질 암력내에 세맥상의 섬장암이 수반되어 산출된다. 단사휘석은 Mg/(Mg+Fe)비가 0.76-0.78, 사장석은 An_{79-83}로 조면현무암력의 것과 유사한 조성을 보인다. 섬장암질 세맥중의 알카리장석은 High- sanidine(Fig.4-3) 계열의 조성을 보인다.

동도의 집괴암층 위에 놓인 조면안산암들은 담회색을 띠며 사장석과 단사휘석 외에 갈색의 흑운모와 소량의 알카리장석이 반정을 이루고 있다. 흔히 취반상조직을 띠며 석기부는 완정질의 조면암질 조직을 보인다. 큰 사장석 반정은 정 또는 진동상(oscillatory) 누대구조를 이룬 An_{58-34}의 조성을 보이며, 석기부의 알카리장석 미정들과 유사한 조성을 가진 High-sanidine의 얇은 주변부로 둘러싸여 있다(Plate 5a). 단사휘석은 반정의 경우 Mg/(Mg+Fe)비가 0.78 정도이고, 둥글고 불규칙한 경계를 가진 석기중의 세립 결정은 0.76으로 큰 차이는 보이지 않는다. 또한 조면현무암류의 것과도 별 차이가 없다.

서도의 동측을 따라 하부에 분포된 조면안산암 내지 조면암질 암들은 동도 상부에 놓인 것과 암상은 유사하지만 성분은 약간 펠식(felsic)하다. 사장석 보다는 알카리장석 반정이 우세하고 단사휘석 외에 갈색의 흑운모 반정이 산출되며(Plate 5b), 종종 수 cm 크기의 작은 심성 포획암

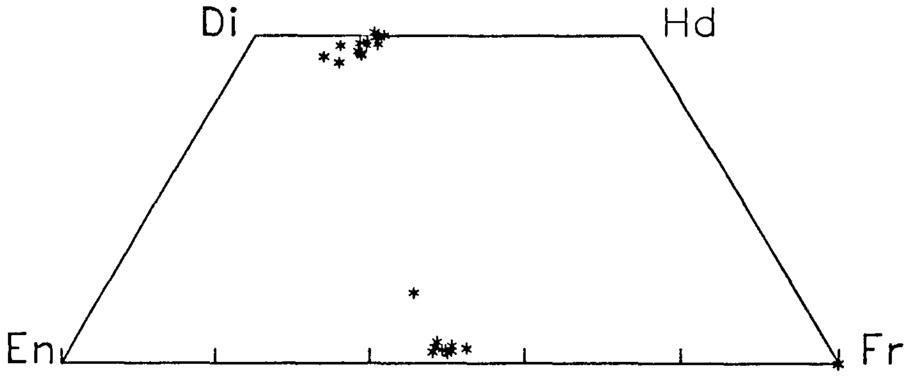


Figure 4-2. The enlarged triangular diagram of Wo-En-Fs system showing the compositions of pyroxenes from tokto volcanic rocks. Solid circles : pyroxenes of basaltic fragments ; solid squares : trachyandesites ; open triangles : trachytes.

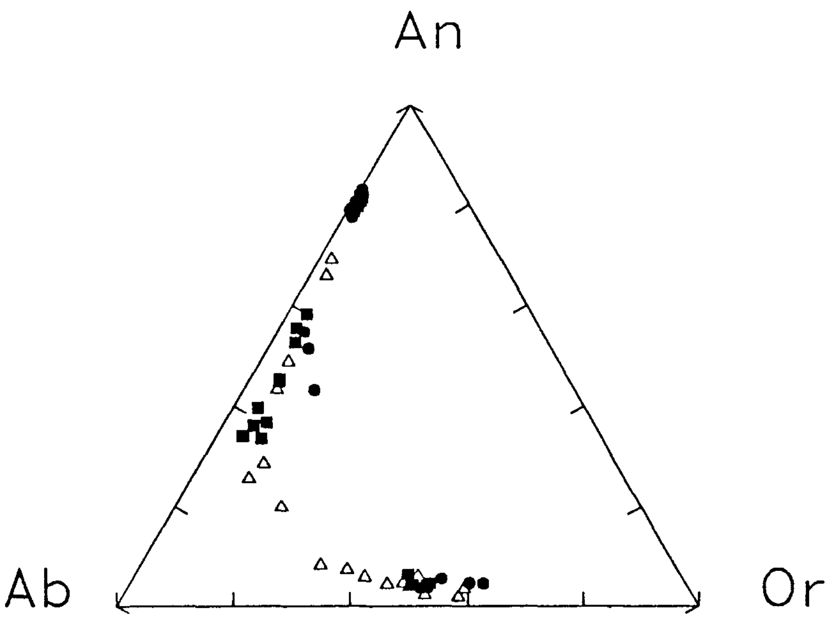


Figure 4-3. An-Ab-Or triangular diagram for feldspar compositions. Symbols are the same as in Fig. 2.

편이 산출되기도 한다. 사장석 반정의 경우 흔히 An 함량이 매우 높은 중심부 핵(An_{80} 정도)이 안데신(An_{34} 정도) 성분의 주변부로 둘러싸여 있어 중심 핵부분의 사장석이 심성 포획암편 또는 초기의 덜 분화된 보다 매픽한 암석에서 유래된 외래 결정임을 지시하고 있다. 단사휘석 반정의 Mg/(Mg+Fe)비는 0.74로 동도의 것에 비해 약간 낮다.

서도지역의 집괴암내에 포함된 역들의 종류는 대체로 동도의 것과 유사하다. 상부에 놓인 응회암층중 동부지역의 것은 분급이 매우 양호한 괴상의 세립질 응회암이 주이고 하부쪽에 세립의 화산력(lapilli)을 포함한 라필리질 응회암이 발달되어 있다. 북서부지역의 경우 앞에서 기술한 바와 같이 하부의 집괴암층에서 위로 감에 따라 응회암층으로 점이되는데 응회암이 우세한 상부에선 역전점이층리에서 정상점이층리로 이화되는 대칭상의 점이층리또는 정상 점이층리가 반복적으로 산출되며 (Plate 5b), 부분적으로는 사층리가 발달되어 있다 (Plate 5c).

조면암은 암녹색 바탕에 알카리장석 반정이 발달된 반상조직의 치밀한 암상을 띠며 주상절리가 현저하다. 알카리장석 외에 소량의 사장석과 단사휘석, 흑운모 등이 반정으로 수반되며 석기부는 전형적인 조면암질 조직을 보인다(Plate 5d). 조면암에서 산출되는 사장석 반정들도 알카리장석 주변부로 둘러싸여 있는데, 중심부의 사장석은 An_{69} 또는 An_{29} 등으로 다양한 성분을 보인다. 또한 취반상조직을 이룬 사장석은 An_{44-49}로 사장석이 여러 기원에서 유래되었음을 나타낸다. 알카리장석 반정은 흔히 나비넥타이형의 연정을 이루고 있으며, 조성은 역시 High-sanidine인데 조면안산암의 것에 비해 Ab함량이 약간 높다. 석기부의 주상 알카리 장석 미정들은 Ab 및 An 함량이 보다 높은 anorthoclase 조성을 보인다(Fig.4-3). 자형으로 잘 산출되는 조면암내의 단사휘석 반정들은 Mg/(Mg+Fe) 비가 0.70에서 0.50 까지 시료에 따라 상당한 변화를 보이지만 전기한 암석들의 것에 비해 상당히 낮은 값을 갖는다. 암맥상의 조면암은 반정의 발달이 미약하거나 무반정질로 잘 발달된 유동구조를 보인다.

4-4. 암석화학조성

27개의 시료에 대해 주성분과 미량 및 희토류원소 성분을 분석하였다. 분석은 기초과학연구지원센터의 XRF와 ICP질량분석기를 이용하였으며 그 결과는 Table 1과 2에 나타내었다. Fig.4-4는 주성분원소에 대한 성분변화도로 전형적인 마그마 분화양상을 보여준다. SiO_2 wt%가 증가함에 따라 $Fe_2O_3{}^t$와 CaO는 규칙적으로 감소하고, Na_2O와 K_2O는 증가한다. SiO_2 wt% 50 까지 MgO는 급격히 감소되고 반대로 Al_2O_3와 P_2O_5는 증가하지만 TiO_2는 일정하다. SiO_2 wt% 50에서 60 사이에선 MgO는 완만하게 계속 감소하며, TiO_2와 P_2O_5가 급격히 감소되고 Al_2O_3는 일정하다. 이는 알카리현무암에서 조면현무암을 거쳐 현무암질 조면안산암으로 분화될 때 단사휘석과 감람석이 주 정출광물이었으며, 현무암질 조면안산암 부터 사장석, 티탄철석, 인회석의 주된 정출이 일어나 조면암까지 분화되었음을 보여주고 있다. 또한 동동의 집괴암층에서 산출되는 조면암력은 가장 분화된 조성을 보이는데 이는 이 화산암들이 한번의 연속적인 정출과정에 의해 형성된 것이 아님을 지시하고 있다. 독도의 화산암들은 울릉도의 것과 함께 K계열의 알카리암인 것으로 알려져 있는데 이번 분석결과 (Fig. 4-5,4-6)도 유사한 경향을 보여준다. 그러나, 동도의 집괴암층에 함유된 현무암질 역중 4개 시료는 대조적으로 Na 계열의 특성을 보인다. Le Bas et al.(1986)의 TAS(total alkali-silica) 분류도(Fig.4-7)를 이용해 분석된 독도 화산암들을 분류해 보면 집괴암내에 함유된 화산암력들은 조면현무암에서 현무암질 조면안산암, 동도의 상부와 서도의 하부에 분포된 용암층은 조면안산암에서 조면암, 응회암층과 서도 상부의 용암층 및 암맥들은 조면암으로 분류된다. Fig.4-8과 4-9는 일부 미량원소의 함량을 각각 chondrite 및 MORB에 대해 표준화 (normalize)하여 도시한 결과인데 현무암질 암편들은 incompatible 원소들이 농집된 전형적인 알카리 OIB의 경향성을 띠며, 산성의 응회암 및 조면암으로 가면서 Ba, Sr, P, Ti 등이 뚜렷하게 감소됨을 보여준다. Fig.4-10은 chondrite성분에 대해 표준화된 희토류원소 성분변화도로 모든 암종들에서 HREE에 비해 LREE가 매우 농집되어 있는 알카리계열의 일반적 경향성을 보인다. Eu의 경우는 현무암

Table 4-1. Major-oxide(wt. %) compositions of Tokto volcanic rocks.

Sample	Type	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Ig.Loss	Total
El 1-4	Ba*	48.79	2.93	18.58	8.50	0.15	2.70	9.03	4.17	1.47	0.90	2.60	99.82
El 1-5	Ba*	51.11	2.32	19.51	7.04	0.15	1.57	7.79	3.12	3.96	0.83	2.54	99.94
El 2-1	Ba*	48.47	2.87	18.45	10.16	0.17	2.34	8.44	2.61	3.47	0.82	2.05	99.85
El 2-4	Ba*	49.61	3.01	17.64	8.46	0.14	2.83	9.04	2.56	3.49	0.86	2.05	99.69
El 2-5	Ba*	47.47	2.87	16.99	10.34	0.38	3.01	8.80	2.55	3.43	0.79	3.16	99.79
El 2-6	Ba*	48.13	2.50	16.22	9.56	0.12	5.91	9.68	2.86	2.86	0.71	1.33	99.88
El 2-8	Ba*	51.95	2.69	18.94	7.21	0.10	2.19	7.57	4.88	1.70	0.92	2.08	100.23
El 2-15	Ba*	48.75	2.97	17.58	9.18	0.20	3.10	8.64	2.66	3.78	0.79	1.99	99.64
BaE FR	(ave)	49.28	2.77	17.99	8.81	0.18	2.96	8.62	3.18	3.02	0.83	2.23	99.86
El 1-6	Gb*	48.36	2.50	16.29	9.33	0.13	5.87	9.45	2.86	2.86	0.73	1.35	99.73
El 1-3	Tr*	65.03	0.66	17.97	2.39	0.08	0.24	0.86	5.72	6.63	0.13	0.07	99.78
El 2-2	Tr*	66.59	0.65	16.05	2.73	0.16	0.48	1.13	5.24	5.99	0.11	0.34	99.47
Tr Fr	(ave)	65.81	0.66	17.01	2.56	0.12	0.36	0.99	5.48	6.31	0.12	0.21	99.63
El 2-7	Trand	56.52	1.76	17.89	5.81	0.12	1.84	4.55	4.20	4.96	0.58	1.28	99.51
El 2-10	Trand	57.60	1.68	18.27	5.80	0.12	1.14	3.30	4.20	6.09	0.72	1.03	99.95
TrandE	(ave)	57.06	1.72	18.08	5.81	0.12	1.49	3.93	4.20	5.53	0.65	1.16	99.73
W 029	Trand	59.60	1.59	18.80	3.49	0.06	1.01	3.18	4.40	6.29	0.52	0.70	99.64
W 030	Trand	58.94	1.22	17.98	4.47	0.16	1.33	3.07	4.68	6.25	0.37	1.02	99.49
TrandW	(ave)	59.27	1.41	18.39	3.98	0.11	1.17	3.13	4.54	6.27	0.45	0.86	99.57
Wl 2-4	Ba*	50.50	2.64	18.68	7.04	0.18	2.14	7.67	2.94	3.86	1.13	3.12	99.90
Wl 3-5	Ba*	48.70	2.65	17.42	8.93	0.32	2.21	7.72	2.97	3.86	1.10	3.65	99.53
BaW Fr	(ave)	49.60	2.65	18.05	7.99	0.25	2.18	7.69	2.96	3.86	1.12	3.39	99.72
Wl 2-2	Tuff	56.65	0.57	17.44	3.95	0.07	0.86	1.58	3.73	4.79	0.21	10.04	99.89
Wl 3-1	Tuff	55.90	0.72	18.02	5.82	0.06	0.54	1.23	5.19	5.84	0.23	6.27	99.82
Tuff	(ave)	56.27	0.65	17.73	4.89	0.07	0.70	1.41	4.46	5.32	0.22	8.16	99.86
Wl 1-2	Tr	58.55	0.27	18.47	5.25	0.20	0.15	1.63	6.55	5.84	0.04	2.35	99.30
Wl 1-4	Tr	59.47	0.25	18.75	4.74	0.14	0.16	1.48	6.35	5.89	0.06	1.94	99.23
Wl 2-3	Tr	58.98	0.49	18.79	4.87	0.20	0.47	2.02	5.71	6.01	0.14	2.03	99.71
Wl 3-6	Tr	59.99	0.47	17.80	5.63	0.18	0.33	2.05	6.01	5.97	0.14	1.04	99.61
W - 3	Tr	55.83	1.38	17.48	6.33	0.15	1.75	4.46	4.70	4.48	0.38	2.73	99.67
W - G	Tr	59.12	0.45	18.21	5.51	0.19	0.38	1.90	4.92	5.84	0.13	2.85	99.50
W 2(2)	Tr**	60.92	0.46	18.77	4.40	0.10	0.32	1.53	5.19	6.11	0.13	1.38	99.31
W 027	Tr**	57.94	0.21	18.28	5.36	0.19	0.12	1.69	6.86	5.97	0.05	2.15	98.82
Tr	(ave)	58.85	0.49	18.32	5.26	0.17	0.46	2.10	5.79	5.76	0.13	2.06	99.39

Ba: basaltic, Gb: gabbroic, Tr: trachytic, Trand: trachyandesitic,
*: fragments in agglomerate, **: dike

Table 4-2. Trace and REE compositions of Tokto volcanic rocks.

Sample	Type	Li	Be	Sc	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Mo	Cd	Sn	Sb
EI 1-4	Ba*	11.50	2.13	5.49	6.31	30.92	42.04	123.41	118.03	31.51	84.39	1395.36	28.35	385.65	124.51	3.35	0.17	2.50	0.10
EI 1-5	Ba*	6.10	1.55	4.51	2.46	17.94	16.56	21.64	81.17	29.42	73.87	1350.42	23.50	388.03	102.98	2.88	0.14	2.23	0.14
EI 2-1	Ba*	12.50	3.19	11.15	17.90	40.36	41.61	102.94	124.32	34.34	91.46	1125.58	29.52	339.77	109.88	3.32	0.18	2.44	0.21
EI 2-4	Ba*	13.90	2.87	9.37	14.24	28.35	20.29	34.02	149.25	31.66	99.68	1308.16	31.48	423.23	112.41	4.36	0.31	2.36	0.08
EI 2-5	Ba*	11.00	3.19	9.50	20.41	36.95	41.94	44.46	139.93	33.34	97.87	1278.64	28.89	407.17	111.63	4.20	0.46	2.65	0.18
EI 2-6	Ba*	17.00	3.45	7.19	21.00	14.15	17.49	11.63	108.49	31.94	62.16	959.56	29.44	417.41	116.84	3.82	0.18	2.34	0.18
EI 2-8	Ba*	5.90	3.37	3.88	3.20	21.65	22.00	17.22	97.01	29.59	41.20	933.34	24.60	476.71	139.04	4.36	0.11	3.08	0.11
EI 2-15	Ba*	9.30	3.36	5.76	18.47	30.54	31.67	81.68	129.47	29.34	86.37	1004.27	23.25	397.81	110.16	6.20	0.26	2.80	0.24
EI 1-6	Gb*	7.00	1.56	3.62	78.49	32.45	71.53	59.80	86.17	17.08	60.28	557.08	12.65	260.03	88.60	1.07	0.15	2.30	0.16
EI 1-3	Tr*	14.10	3.56	0.62	7.08	0.97	1.87	0.67	63.69	24.82	182.90	13.26	10.04	1038.54	191.52	0.003	0.23	3.42	0.13
EI 2-2	Tr*	10.50	3.32	1.20	1.99	0.76	1.18	0.76	44.16	18.98	115.75	25.15	13.34	331.04	147.18	0.53	0.18	2.67	0.09
EI 2-7	Trand	11.90	3.00	7.74	6.93	26.85	22.94	70.49	110.43	29.54	90.65	1226.56	29.38	410.34	109.55	4.55	0.32	2.87	0.16
EI 2-10	Trand	24.70	1.70	7.66	7.45	7.91	5.53	8.66	92.21	32.53	130.80	1094.78	22.14	425.54	120.97	2.18	0.27	2.05	0.23
WI 029	Trand	8.60	0.87	2.56	5.89	7.00	4.75	5.66	63.20	28.13	145.62	640.87	21.49	511.48	138.25	1.46	0.13	2.80	0.25
WI 030	Trand	25.90	4.85	1.82	7.33	5.83	4.73	6.33	79.43	30.10	169.82	612.22	26.85	648.67	163.88	5.52	0.05	3.57	0.31
WI 2-4	Ba*	15.60	5.01	6.80	5.67	20.52	6.63	28.23	147.87	37.30	163.02	1369.65	33.05	610.67	152.43	6.07	0.39	2.80	0.19
WI 3-5	Ba*	8.80	2.38	6.43	3.02	20.03	3.26	20.16	109.22	27.12	131.80	1332.54	28.16	459.75	115.52	4.89	0.25	2.64	0.19
WI 2-2	Tuff	7.70	3.18	5.03	4.24	11.23	7.61	6.05	63.27	27.42	98.20	125.96	24.76	590.05	150.62	4.91	0.50	4.11	0.30
WI 3-1	Tuff	6.50	3.91	5.93	3.74	4.49	3.75	3.83	80.49	29.40	128.00	159.78	18.12	525.27	140.37	5.95	0.30	4.30	0.22
WI 1-2	Tr	29.40	6.92	0.56	4.51	0.61	0.31	3.93	161.96	37.68	242.45	12.16	49.85	944.41	303.40	36.66	0.64	5.67	0.40
WI 1-4	Tr	12.50	4.00	0.45	1.39	0.42	0.16	0.90	140.35	31.64	224.16	26.75	47.11	794.02	255.87	3.69	0.36	4.78	0.17
WI 2-3	Tr	31.00	5.81	1.41	5.69	3.40	2.57	6.86	124.15	34.44	205.55	105.36	42.03	828.15	227.84	8.66	0.38	4.88	0.27
WI 3-6	Tr	14.00	4.48	1.78	4.15	2.48	1.13	1.28	150.45	32.27	200.49	80.07	40.25	612.45	184.77	5.74	0.42	3.47	0.13
WI - 3	Tr	23.30	4.25	5.79	41.02	18.49	21.69	35.64	146.80	35.53	108.99	497.29	39.98	533.38	152.86	4.60	0.20	3.23	0.14
WI - G	Tr	16.10	4.92	2.82	8.62	2.31	1.86	4.47	124.38	32.25	150.27	51.37	32.06	667.16	223.53	4.36	0.36	4.76	0.20
WI 2(2)	Tr**	25.60	3.99	1.43	10.68	4.10	5.86	6.25	127.14	38.29	188.03	85.31	37.94	742.49	221.77	2.74	0.57	4.59	0.19
WI 027	Tr**	17.60	4.60	15.85	2.75	0.35	0.31	3.30	123.21	28.66	197.20	4.29	28.68	774.78	240.25	6.68	0.36	5.50	0.33

Table 4-2. (Continued)

Sample	Type	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Yb	Lu	Hf	Ta	Pb	Th	U
El 1-4	Ba*	2.24	1439.82	103.68	177.04	20.88	73.05	11.49	3.48	9.41	1.19	6.35	1.08	3.00	2.56	0.33	7.49	11.41	7.45	13.55	1.95
El 1-5	Ba*	0.68	13330.52	90.67	157.20	18.41	66.69	9.81	3.35	9.07	1.11	5.87	1.02	2.90	2.34	0.31	8.04	10.29	8.38	11.74	2.62
El 2-1	Ba*	0.90	1068.59	91.97	151.67	18.90	68.50	10.67	3.33	9.79	1.23	6.63	1.23	3.05	2.68	0.39	7.57	14.31	16.14	13.54	2.63
El 2-4	Ba*	0.94	1210.74	102.22	172.09	20.51	74.15	12.14	3.51	10.37	1.27	6.45	1.26	3.07	2.79	0.37	8.46	10.43	8.14	12.60	2.78
El 2-5	Ba*	1.01	1153.29	102.00	172.82	20.68	74.33	11.63	3.55	10.26	1.26	6.33	1.23	3.17	2.45	0.37	8.45	10.66	20.87	12.64	2.55
El 2-6	Ba*	5.09	1488.85	101.86	180.28	21.30	79.81	11.39	4.57	10.60	1.33	7.08	1.25	3.19	2.47	0.41	8.27	10.74	9.11	12.73	2.68
El 2-8	Ba*	2.78	961.40	89.37	161.28	17.91	63.45	9.25	2.78	8.46	1.01	5.64	1.02	2.57	2.00	0.28	9.64	12.40	12.90	9.96	3.00
El 2-15	Ba*	0.89	938.97	82.19	142.42	16.83	58.77	9.65	2.95	8.12	1.05	5.68	1.00	2.49	2.10	0.31	8.10	10.99	26.15	10.57	2.64
El 1-6	Gb*	1.45	561.98	54.72	83.38	10.62	38.03	5.44	1.77	5.19	0.59	3.12	0.62	1.42	1.17	0.15	6.42	9.72	12.42	7.60	2.46
El 1-3	Tr*	0.73	26.20	45.15	86.18	8.83	26.23	3.84	0.69	3.39	0.39	2.18	0.48	1.44	1.66	0.25	17.78	17.52	16.11	13.42	2.91
El 2-2	Tr*	0.70	40.23	78.14	117.59	14.30	47.33	6.32	1.10	4.81	0.63	3.68	0.63	1.87	1.68	0.24	8.46	16.07	6.36	12.40	1.83
El 2-7	Trand	0.77	1173.37	93.41	157.08	19.25	70.45	10.64	3.47	9.80	1.21	6.43	1.23	3.15	2.44	0.37	8.25	10.02	8.83	12.00	2.53
El 2-10	Trand	0.88	1543.67	90.47	148.99	17.77	63.48	10.00	4.42	7.55	1.00	5.05	0.89	2.40	1.96	0.27	8.37	11.06	13.96	12.54	2.54
Wl 029	Trand	1.67	1041.11	87.44	146.85	18.19	60.89	8.87	3.49	7.69	0.89	5.13	0.92	2.36	2.12	0.25	10.20	12.57	11.30	14.29	3.08
Wl 030	Trand	2.64	801.39	101.51	159.95	18.40	60.24	8.53	2.97	7.53	0.98	5.37	1.02	2.95	2.31	0.34	11.83	13.54	14.59	16.23	3.75
Wl 2-4	Ba*	1.09	1253.15	121.71	205.52	23.09	79.56	11.37	3.48	10.85	1.24	6.67	1.10	3.14	2.69	0.32	10.93	12.32	15.98	15.17	3.41
Wl 3-5	Ba*	1.34	1318.38	116.60	198.84	24.06	84.16	12.28	3.93	10.18	1.26	7.09	1.24	3.16	2.84	0.35	10.26	13.25	19.92	17.31	3.50
Wl 2-2	Tuff	1.96	286.59	74.79	119.53	15.81	55.32	8.69	1.41	7.84	1.07	6.52	1.26	3.20	3.00	0.44	13.47	15.90	9.78	16.78	7.48
Wl 3-1	Tuff	1.66	388.10	55.55	100.29	13.24	48.13	8.61	1.57	6.79	1.05	5.53	1.06	2.70	2.59	0.35	12.89	15.92	9.06	17.58	4.21
Wl 1-2	Tr	2.77	2.33	162.99	266.80	31.81	106.17	17.19	0.89	14.65	2.09	11.41	2.05	5.95	5.43	0.77	17.91	23.61	15.66	27.75	5.00
Wl 1-4	Tr	3.29	7.02	176.80	293.86	33.12	108.82	15.53	1.16	14.60	1.90	10.74	2.06	5.75	5.07	0.71	16.68	23.43	16.77	29.57	5.61
Wl 2-3	Tr	1.80	304.05	120.26	159.52	23.16	82.75	13.53	1.57	11.51	1.64	9.59	1.80	4.70	4.50	0.62	16.42	19.40	14.23	24.23	4.73
Wl 3-6	Tr	3.32	384.15	128.64	216.08	25.62	93.59	14.82	2.55	13.25	1.75	9.68	1.76	4.63	4.35	0.65	12.68	15.83	9.75	20.09	4.11
Wl - 3	Tr	1.58	729.11	117.16	190.79	22.63	79.26	12.86	3.06	12.10	1.48	8.22	1.49	4.08	3.53	0.51	10.07	12.29	15.32	15.74	2.87
Wl - G	Tr	0.82	136.68	98.28	150.27	19.79	69.07	11.52	1.35	9.33	1.32	7.49	1.33	3.69	3.56	0.49	14.20	19.39	8.81	15.70	2.86
Wl 2(2)	Tr**	1.33	200.32	118.53	192.54	23.85	77.74	13.53	1.74	11.39	1.59	9.10	1.50	4.23	4.06	0.50	14.94	19.04	9.84	20.18	3.15
Wl 027	Tr**	2.16	5.48	73.50	137.87	17.34	61.30	11.05	0.67	9.41	1.36	8.37	1.69	4.51	4.11	0.58	18.40	29.83	14.31	10.33	4.54

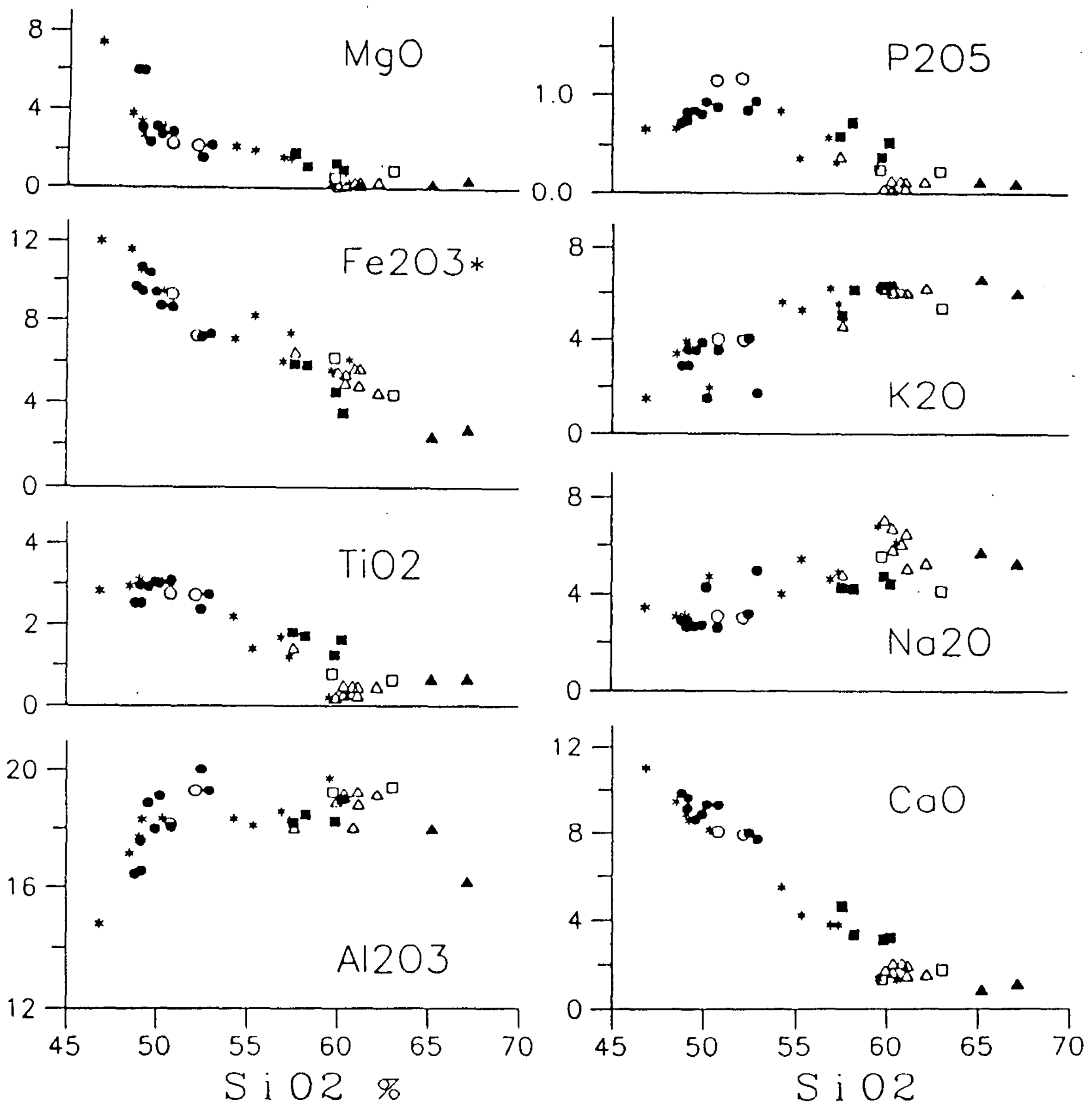


Figure 4-4. Harker Variation diagrams for volcanic rocks from Tokto island. Solid circles and triangles : basaltic and trachytic fragments from agglomerate, respectively ; solid squares : trachyandesites ; open squares : tuffs ; open triangles : trachytes : stars : data from Kim (1988).

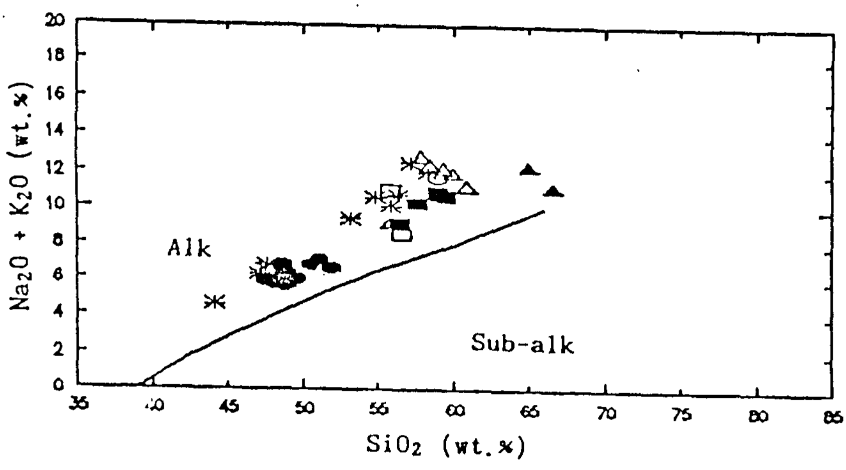


Figure 4-5. Total alkalis versus silica diagram. The boundary between the alkalic and sub-alkalic fields is from Irvine and Baragar (1971). Symbols are the same as in Fig. 4.

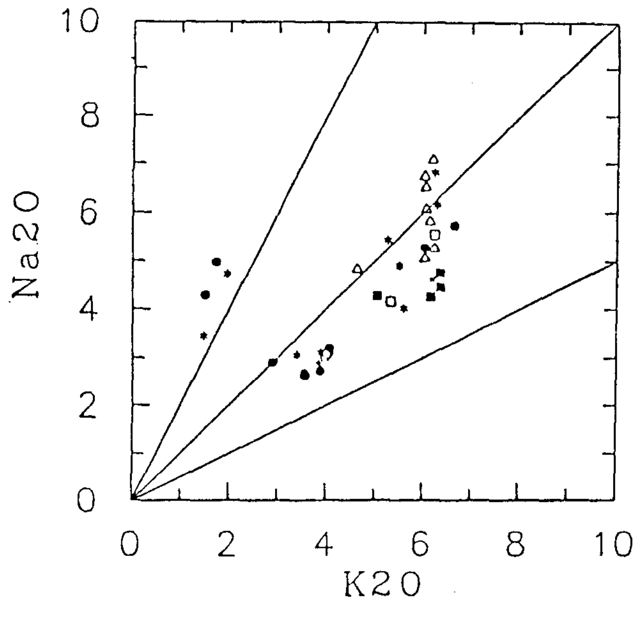


Figure 4-6. Variation of Na_2O (wt.%) versus K_2O (wt.%). Symbols are the same as in Fig. 4.

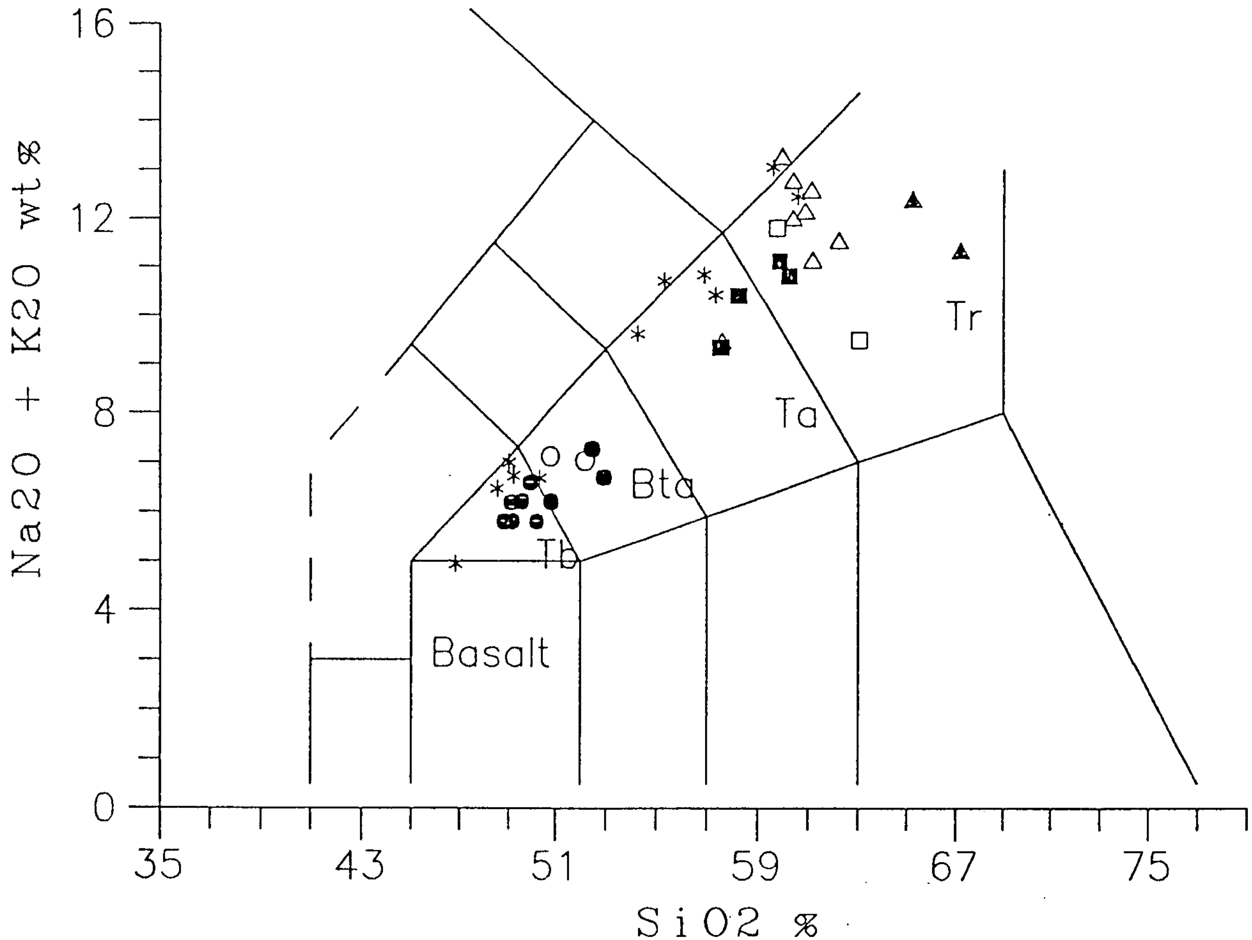


Figure 4-7. Nomenclature for volcanic rocks using total alkali versus silica(TAS) diagram(after Le Bas et al., 1986). Symbols are the same as in Fig. 4.

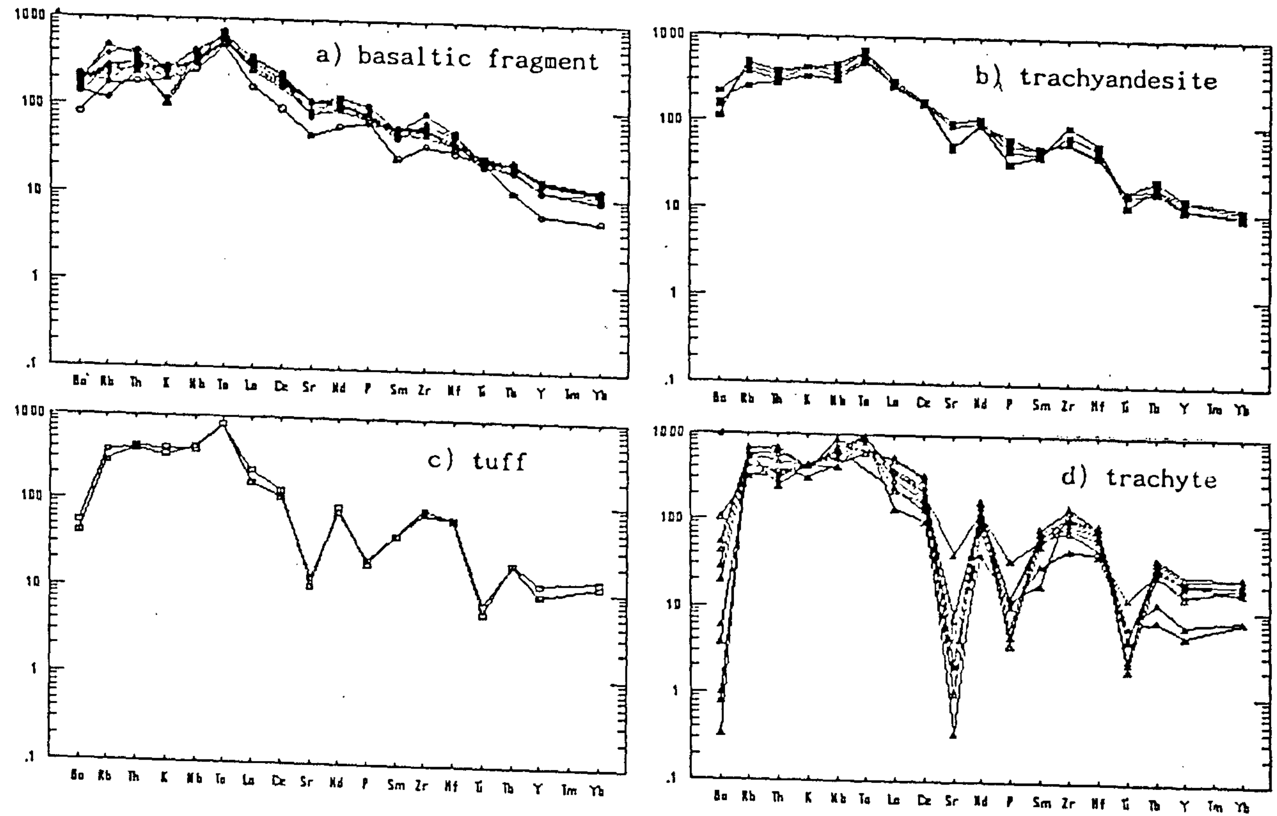


Figure 4-8. Spiderdiagrams according to Thompson et al. (1984).

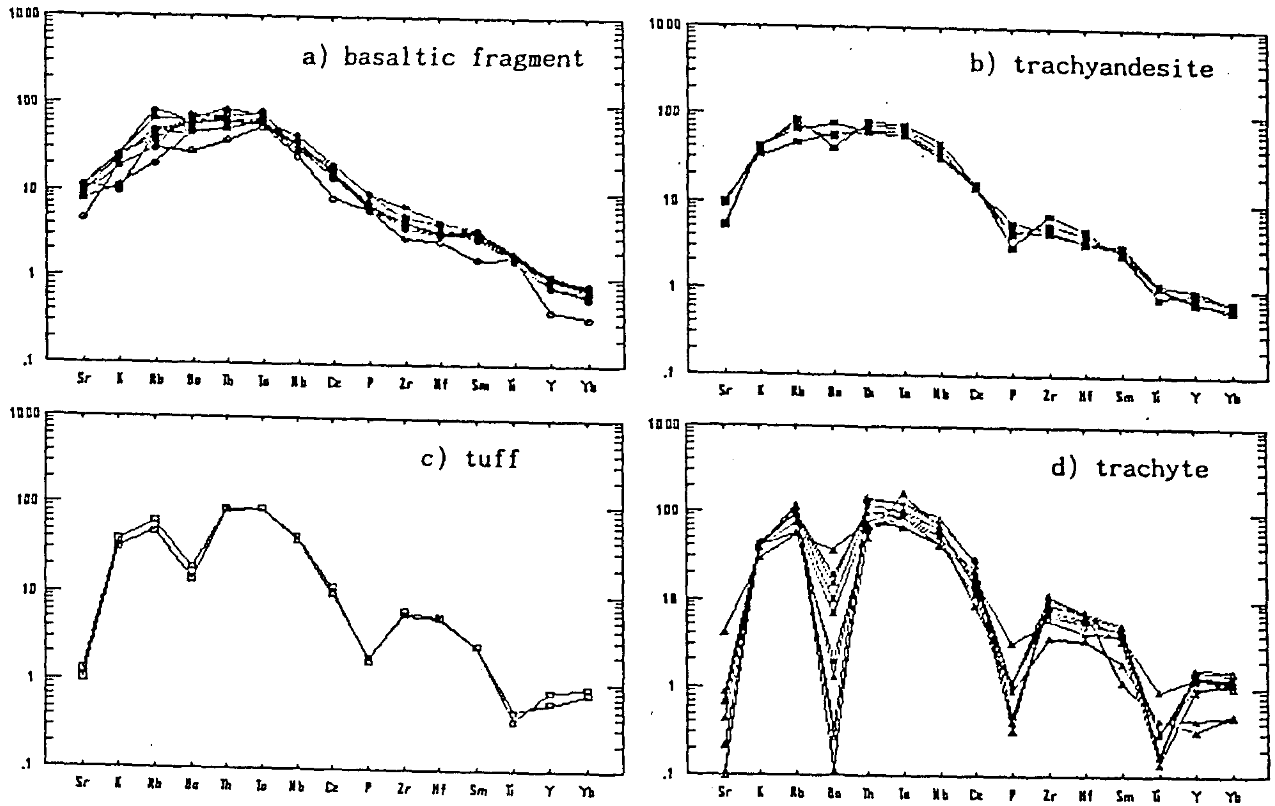


Figure 4-9. MORB-normalized trace element variation diagram according to Pearce (1983).

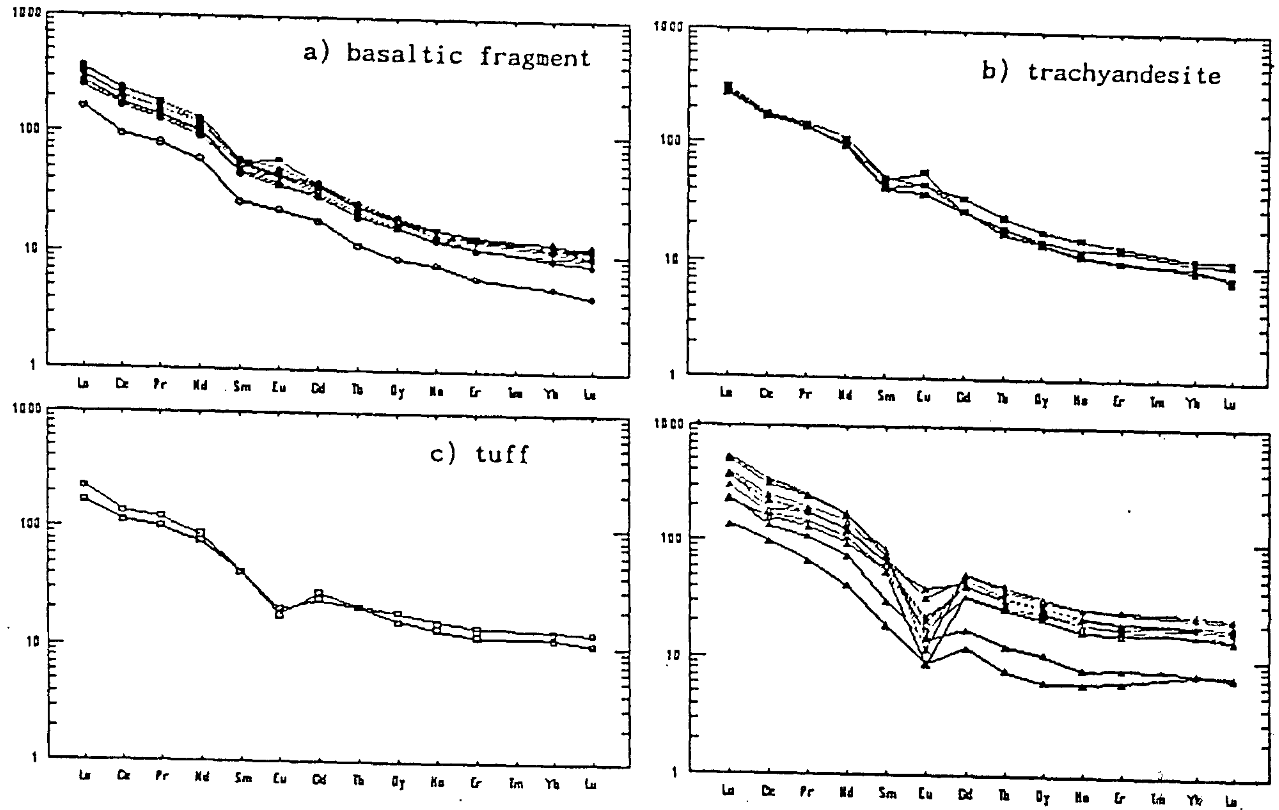


Figure 4-10. Chondrite-normalized REE abundances.

류와 조면안산암은 없거나 미약한 양의 이상치를 보이는데 비해 응회암과 조면암류는 뚜렷한 음의 이상치 (특히 후자에서 더 현저한 이상치)를 나타낸다.

4-5. 결과토의 및 결론

독도화산섬의 지질을 요약하면 최하부에 놓인 알카리현무암질 내지 조면현무암질의 집괴암층위에 조면안산암질 용암이 분출하였고, 다시 그위에 집괴암과 화산회질 응회암이 피복한후 조면암질 용암이 분출하였다. 조면암질 용암은 열개를 충진한 암맥상으로도 산출되며, 분출이후 여러 방향으로 발달된 단층과 후기의 침식활동에 의해 급경사의 지형이 형성되었다. 특히 분출후에 수반된 함몰로 동도 가운데에는 함몰화구와 이를 중심한 방사상의 단층이 발달되어 있다. 조면암은 현재 서도에만 두껍게 분포되어 있는데 이는 침식에 의한 결과인지 조면암의 분출시기에 화구가 서도쪽으로 이동된 것인지는 확실치 않다.

화산암류들의 진화과정을 보면 현무암질에서 조면안산암을 거쳐 조면암으로의 분화가 반복되는 경향을 보인다. 화학조성의 변화도 분화과정을 뚜렷하게 보여준다. 특히 미량원소의 변화경향은 감람석과 휘석의 초기정출로 Ni, Cr, Co 등이 심하게 결핍되어 있으며, 산성암으로 가면서 사장석, 인회석, 자철석의 정출에 의해 잔류 마그마내에 Ba, Sr, P, Ti 등의 성분이 고갈되었음을 보여준다. 희토류원소 변화도에서의 Eu 이상치는 사장석의 분별정출이 중성암 (조면안산암류)에서부터 현저하게 일어났음을 지시하는데 이는 주성분 및 미량원소의 변화양상, 현미경하에서 관찰된 암석기재적 특성 등과 잘 부합되고 있다. 또한, 미량 및 희토류원소 화학조성은 도호환경과는 구별되는 알카리 OIB의 경향성을 보인다.

Explanations of Plates.

Plate 1. a) View to Tokto island, which consists of two islands called Dong-do(right) and Seo-do(left) and a few tens of rocks. b) Agglomerate beds from Dong-do. c) Agglomerate beds showing sequence of massive or thick-bedded(lower) to thin-beded(upper) units.

Plate 2. a) Thick-bedded agglomerates beds from Dong-do. b) Lens-shape, light-colored massive tuff intercalated in agglomerate beds. c) Crater in the center of Dong-do showing pyroclastic beds(lower) and trachytic lava flows(upper) cross-cut by small faults and breccia(white). d) Trachytic dike intruded into pyroclastic beds.

Plate 3. a) View to Seo-do(west island) from south showing more steeply dipping pyroclastic beds. b) View to Seo-do from east showing pyroclastic beds overlain by columnar-jointed trachytic lava flow. Light-colored tuff bed on uppermost part of the pyroclastic beds shows flame-like structures. c) Sequence of massive agglomerate bed to thin-beded tuff beds. d) Trachytic dike and two parallel faults cross-cutting the pyroclastic beds and trachytic lava flow.

Plate 4. a) Agglomerate beds showing the intercalated tuff layer and light-colored trachytic fragments. b) Photomicrograph of trachybasaltic fragment showing the zoned plagioclase phenocryst. c) Agglomerate beds showing reverse grading. d) Photomicrograph of gabbroic fragment showing the granular texture composed of clinopyroxenes, plagioclases(white), ilmenites(black), biotites (brown) and some hornblendes.

Plate 5. a) Photomicrograph of trachyandesite showing the plagioclase phenocryst(white) mantled by sanidine(dirty). b) Symmetrically graded(reverse to normal) tuff beds from Seo-do. c) Fine tuff beds, showing the cross laminations, overlain lithic-rich tuff. d) Photomicrograph of trachyte showing the trachytic texture in which rectangular sanidine and polygonal clinopyroxene phenocrysts are surrounded by small aligned alkali feldspars.

Plate 1.

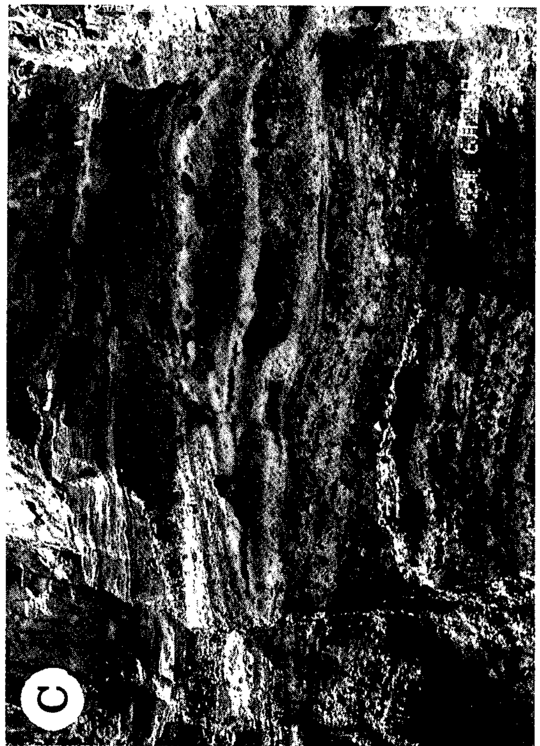


Plate 2.

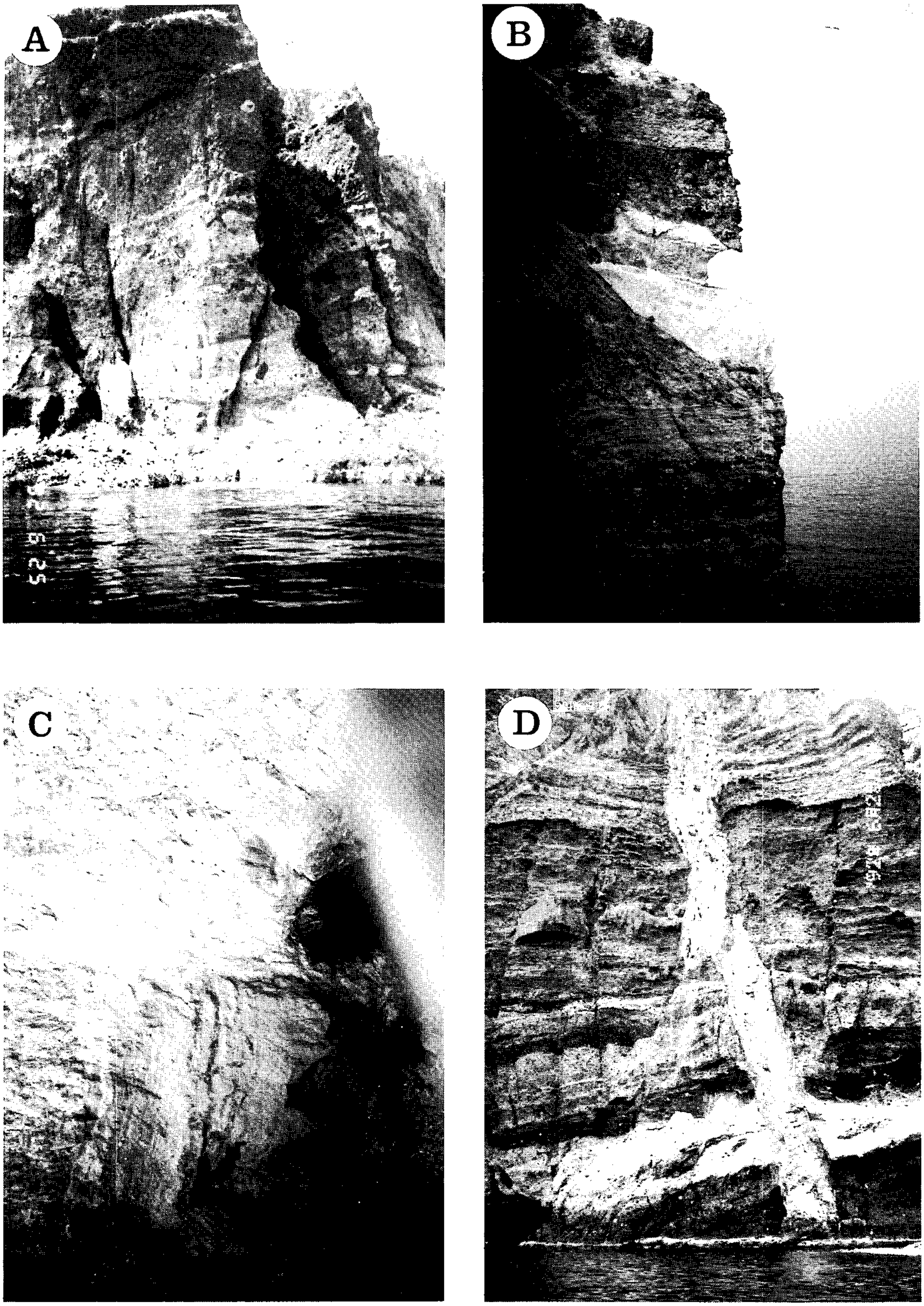


Plate 3.

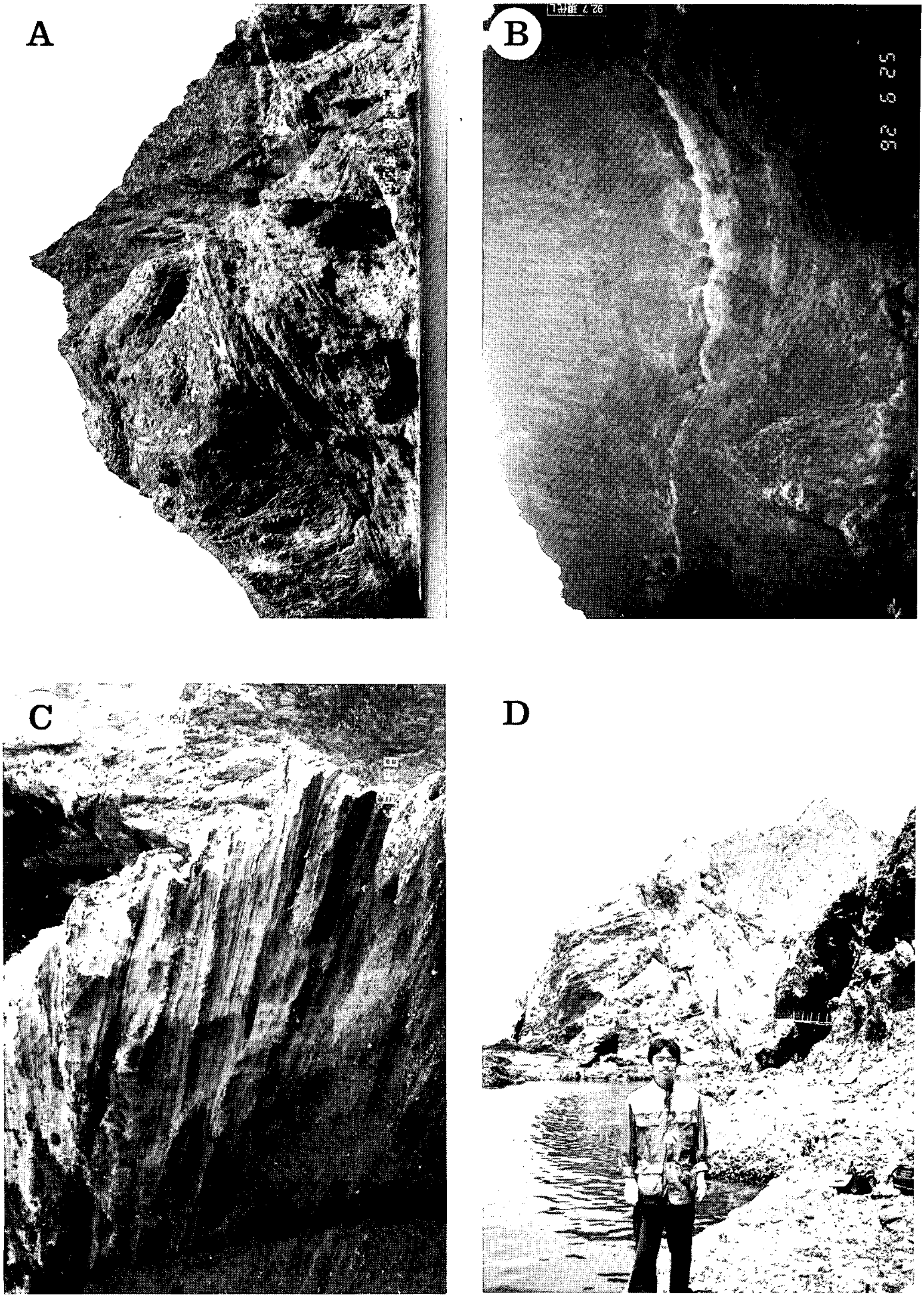


Plate 4.

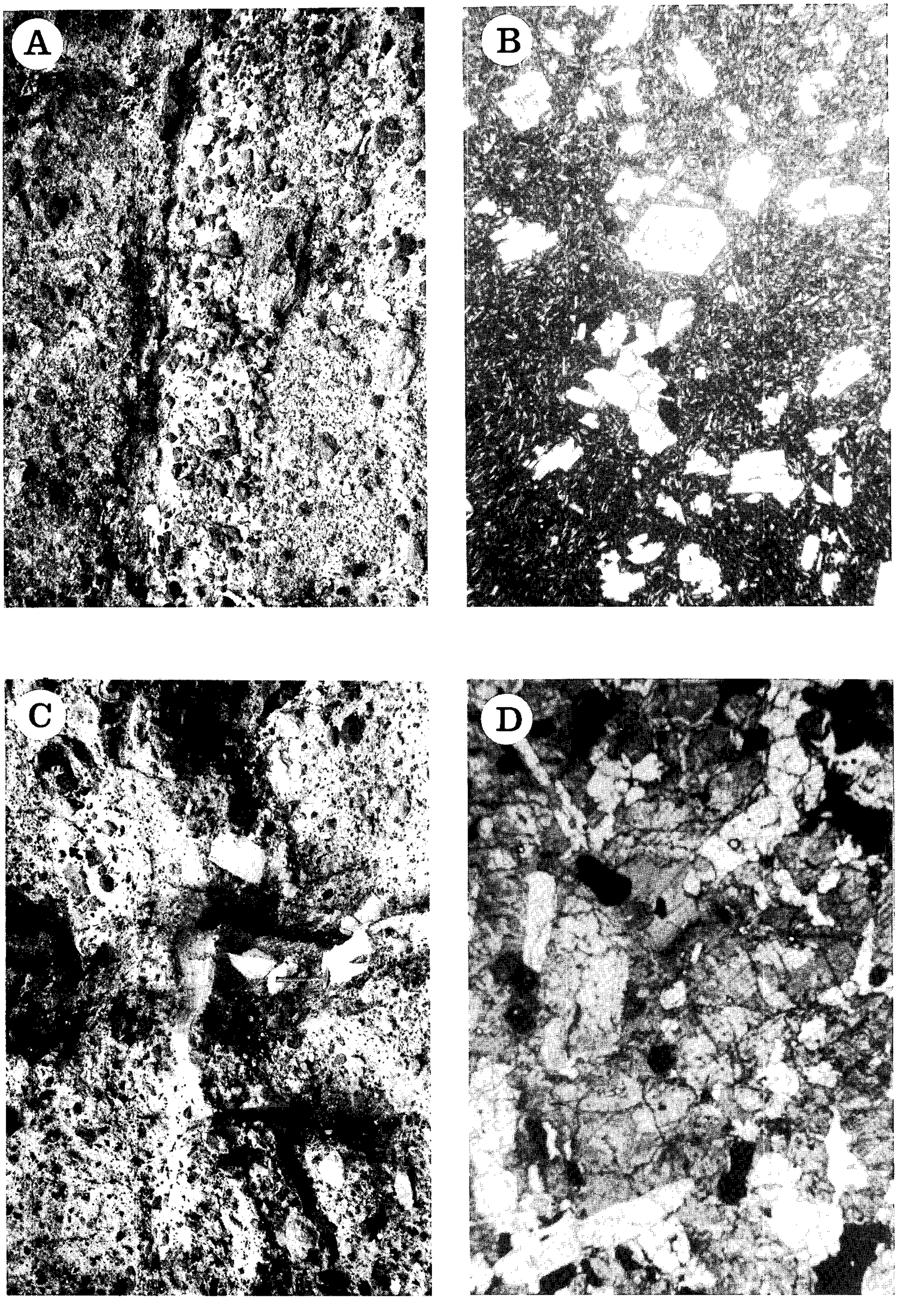
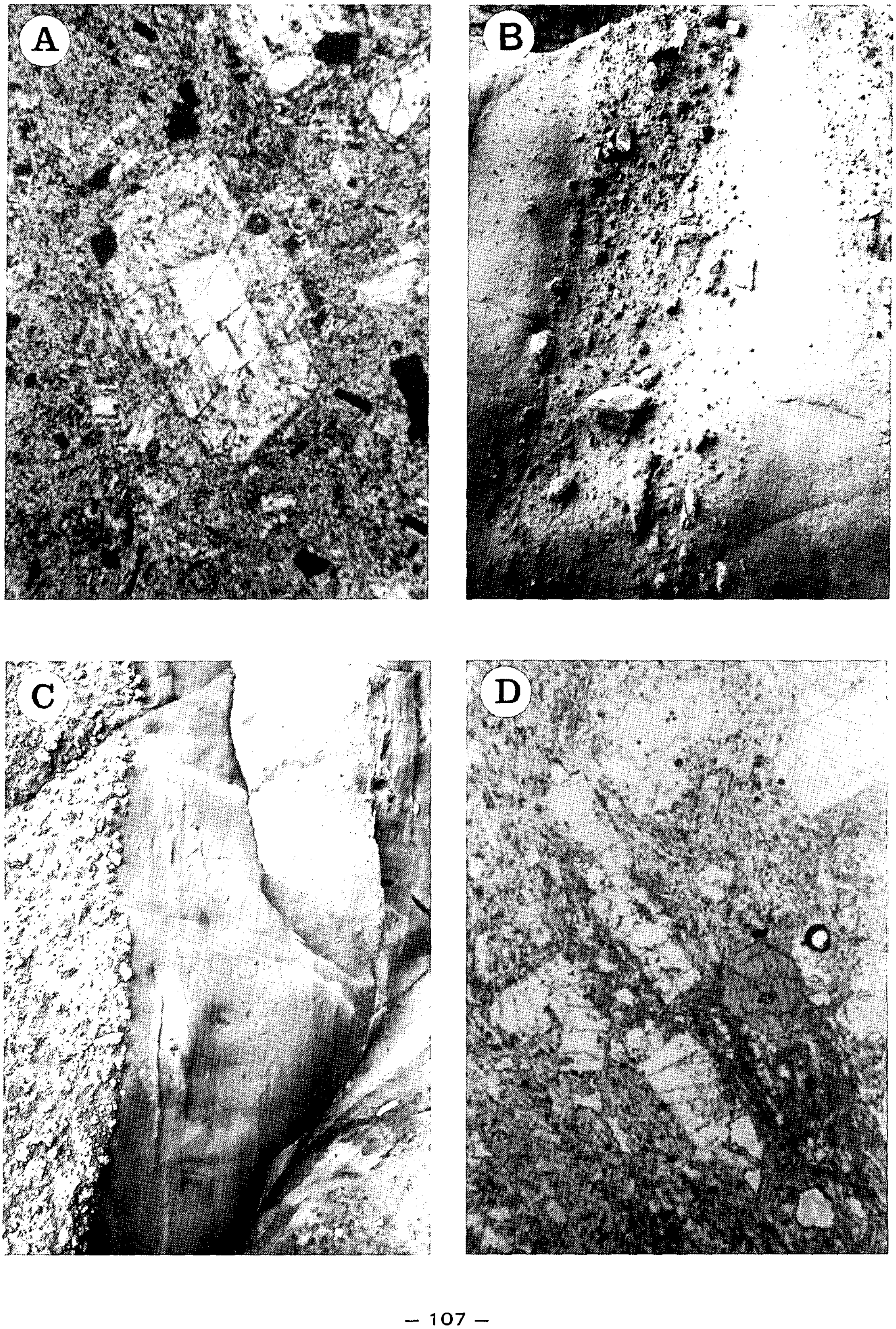


Plate 5.



제 5 장

독도에서의 고지자기

제 5 장 독도에서의 고지자기

5-1. 서 론

독도는 야외산상과 내부구조 및 암층경계면의 특징, 수직 및 수평적 암상변화에 의해 화산암층 및 층서가 분류된다. 본 연구에서는 화산활동시기(현재 연구가 진행중임)와 관련한 자기층서 및 화산작용과 관련된 고지자기학적 정보의 획득을 위하여 13개 지점에서 채취한 47개의 원통형 시편을 이용하여 회반자력계에 의한 자연잔류자화측정과 열소자기를 이용하여 잔류자화측정하고 표준 고지자기 자화처리방법에 의해 자료를 분석하였다.

5-2. 연구방법

고지자기 연구를 위하여 13 sites에서 47개의 직경 및 길이가 2.5 cm인 원통형 시편을 채취하여 다음 순서에 의하여 실험을 수행하였다.

1)자연잔류자화(Natural Remanent Magnetization)를 회반자력계 (Sinsitivity: 1 × 10^{-7} emu/cm^3, Noise Level: 2.5 × 10^{-8} emu/cm^3)를 이용하여 측정

2)열소자자기를 이용하여 100, 150, 200, 300, 400, 500, 550, 580, 600˚C의 열소자 단계에서 시편들을 소자시킨 후 각 단계별 잔류자화를 측정.

3)Fisher Statistics, Principal Component Analysis 등의 표준 고지자기 자료처리 방법에 의하여 측정한 자료를 처리.

5-3. 결 과

연구시료의 자연잔류자화 강도는 18~3170 × 10^{-6} emu/cm^3으로 강한 자연잔류자화를 보유하고 있으며, Stage I 의 WO_2 시료를 제외한 모든 시료들이 역자화를 기록하고 있다(Table 5-1). Fig. 5-1에서 Fig. 5-3은 연구시료들에서 관찰되는 전형적인 열소자 실험결과인 잔류자화 강도의 변화와 잔류자화의 방향변화를 Vector 및 Stereographic Diagrams에 나타낸 것이다. 열소자 단계의 증가에 따른 잔류자화 강도는 150~300°C의 소자 단계까지 증가를 하다가 그 이후의 소자단계에서는 감소함을 보여준다. 이러한 잔류자화 강도의 변화는 암석 생성시 기록된 1차 잔류자화와 반대방향인 현재의 지구자기장에 의한 2차 잔류자화를 제거할 때, 낮은 소자단계에서 일시적인 자화강도의 증가를 보여주다가 감소하는 역전상태를 기록하는 암석에서 관찰되는 전형적인 현상이다. 잔류자화의 방향도 150~300°C의 소자단계에서 급격히 변한 후, 그 이후에서는 소자단계가 증가함에 따라 원점으로 향하는 일정한 방향을 보여주어 150~300°C에서 시료에 기록된 대부분의 2차 잔류자화가 제거됨을 알 수 있다. 모든 역자화를 기록하는 연구시료에서 관찰되는 이러한 급격한 방향변화도 자화강도의 변화와 같이 시료에 기록된 1차 잔류자화와 반대방향인 현재 지구자기장에 의한 2차 잔류자화의 제거에 기인한 것이다. 고지자기 연구결과는 Table 5-1에 요약하였으며, Fig. 5-4는 각 시료채취장소의 상대적인 위치에 대하여 편각, 복각 및 자연잔류자화의 강도를 도시한 것이다. 복각값은 Stage I 의 WO_2 시료를 제외한 모든 시료들이 역자화를 기록하고 있으며, 편각값은 110~330의 변화를 보여 각 용암분출시의 영년변화를 기록하고 있음을 제시하고 있다.

고지자기 연구결과는 독도 암석들이 자기적으로 강한 잔류자화를 보유하고 역자화와 정자화를 모두 기록하고 있어, 앞으로 시료를 체계적으로 채취하여 고지자기 연구를 수행할 경우, 영년변화, 자기층서 등의 매우 좋은 고지자기 연구결과가 기대됨을 제시한다.

Table 5-1. Paleomagnetic results.

Relative Stratigraphy	Sample No.	N	D	I	J	α_{95}	k
Stage III	W07	5	328.2	-54.6	455.7	4.7	270.1
	W06	3	117.7	-54.0	2941.9	4.4	803.7
	W22	5	162.5	-40.6	161.6	5.1	225.3
	W23(U)	3	215.2	-61.8	347.3	7.7	259.7
	W23(M)	3	143.0	-77.7	200.8	10.2	146.2
	W23(L)	1	143.4	-77.1	86.5		
	MEAN	6	164.3	-75.1	699.0	35.7	5.5
Stage II	W05	6	166.2	-57.0	32.4	8.8	59.6
Stage I	W10	4	312.8	-46.5	192.9	6.1	228.3
	W01	4	180.2	-67.0	76.9	9.8	89.3
	W29	3	250.3	-39.1	420.0	39.7	10.7
	W31	5	175.5	-52.2	143.6	5.6	185.0
	W30	3	222.0	-58.8	291.6	30.5	17.4
	W02	2	233.9	18.0	624.9	70.0	14.9
	MEAN	6	232.9	-51.4	291.7	40.9	3.6
	MEAN		194.5	-65.3		35.5	13.1

N: Number of specimens.
D: Declination.
I: Inclination.
J: Intensity.
α_{95}: Cone of confidence about mean direction.
k: Precision parameter (Fisher, 1953).

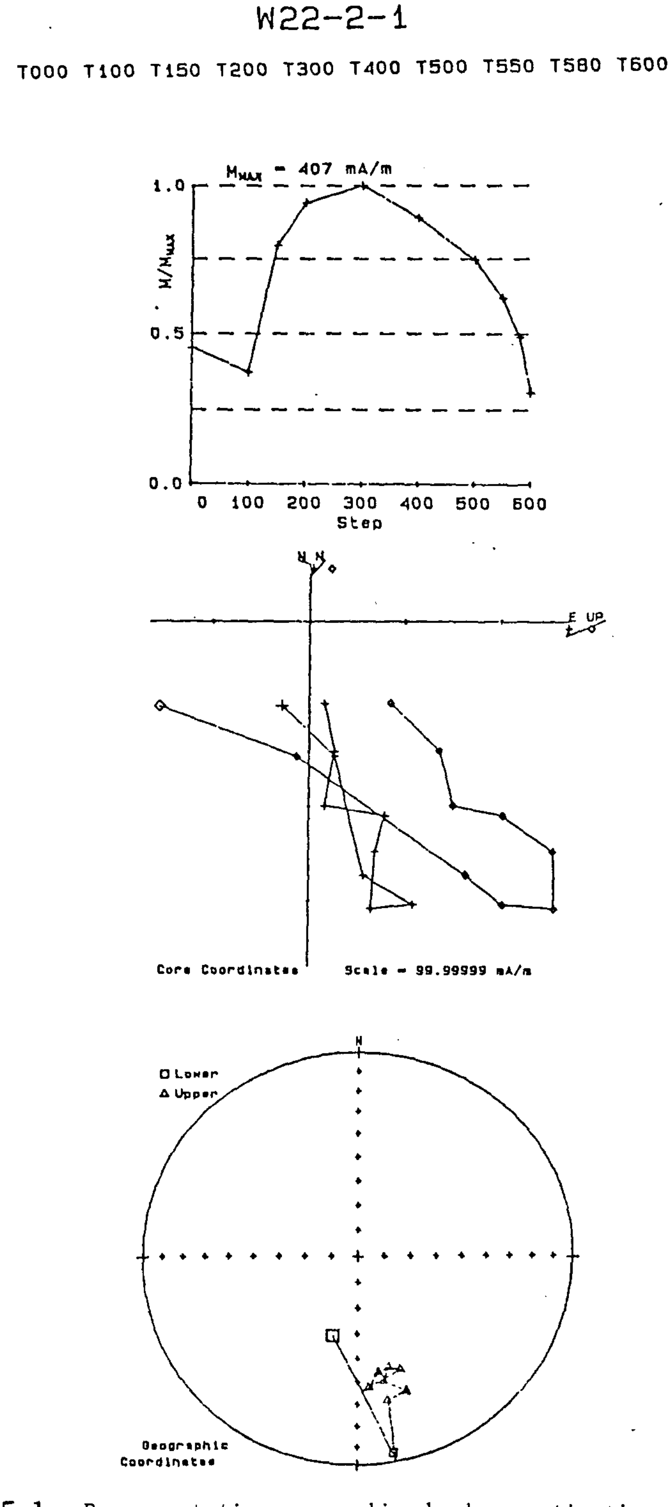


Figure 5-1. Representative normalized demagnetization intensity curve(top), vector diagram(middle), and stereographic plot(bottom) for sample W22-2-1.

W22-5-2

T000 T100 T150 T200 T300 T400 T500 T550 T580 T600

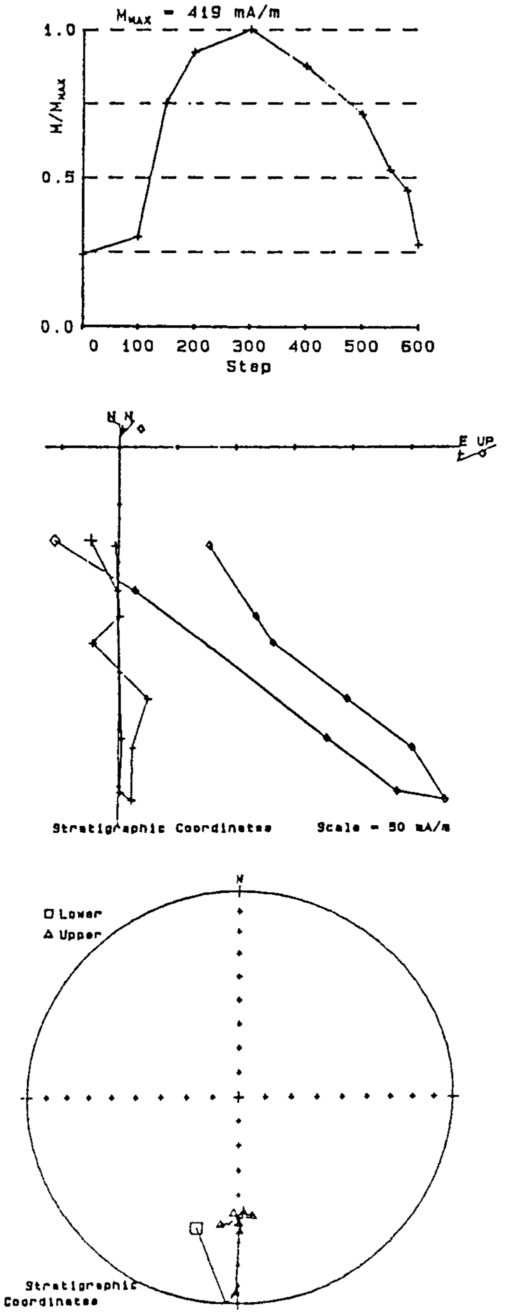


Figure 5-2. Representative normalized demagnetization intensity curve(top), vector diagram(middle), and stereographic plot(bottom) for sample W22-5-2.

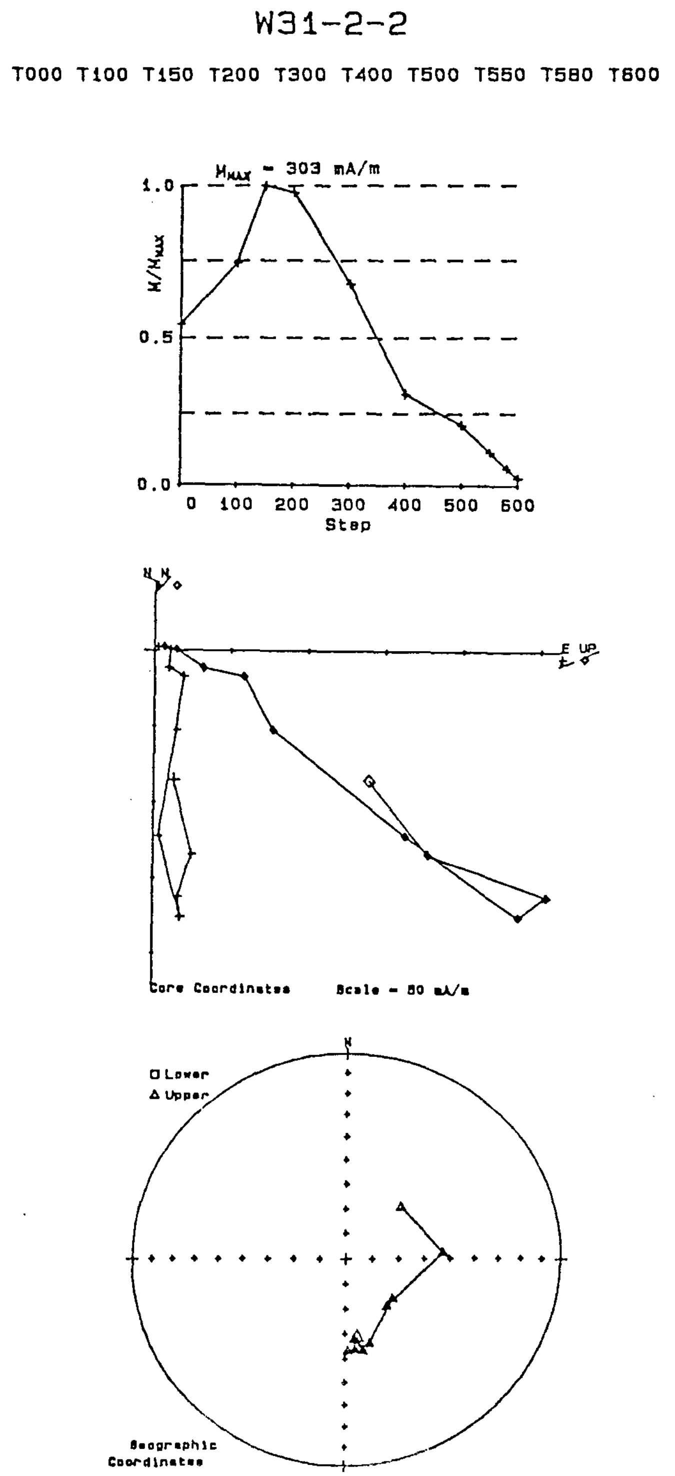


Figure 5-3. Representative normalized demagnetization intensity curve(top), vector diagram(middle), and stereographic plot(bottom) for sample W31-2-2.

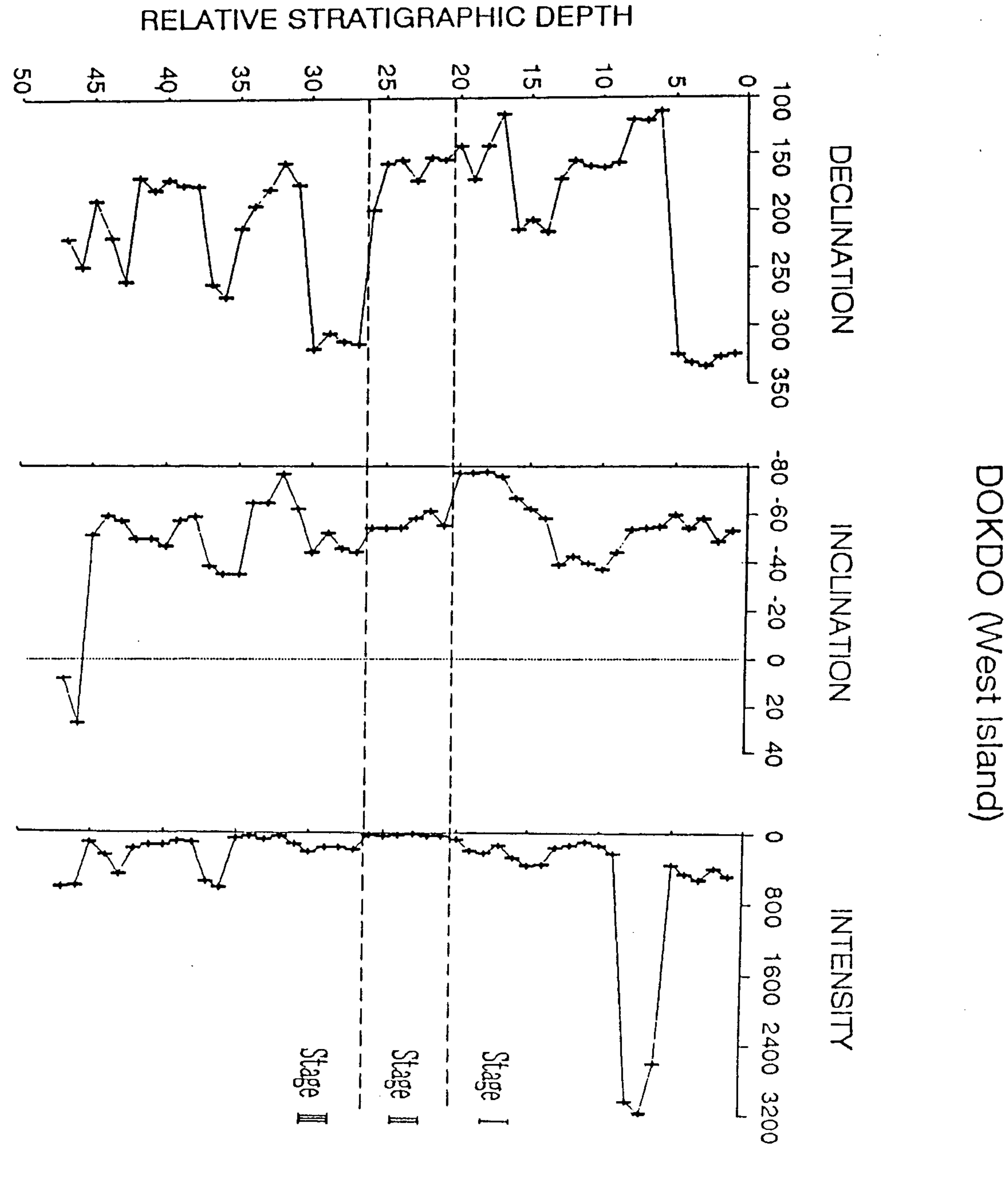


Figure 5-4. Paleomagnetic declination, inclination, and intensity.

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참 고 문 헌

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PART II

RUSSIAN SCIENTIFIC RESULTS

CHAPTER 1

INTRODUCTION

CHAPTER 1. INTRODUCTION

The knowledge of the plausible geohistory of an offshore of the Korean Peninsula are important to understand the fundamental problems on the origin and evolution of the East Sea (Sea of Japan)that at least may turn out the possibility on the seeking and the searching of the various kinds of mineral natural resources.

The Korean Peninsula adjoined by the West Sea (the Yellow Sea)and the East Sea (Sea of Japan) is inserted into the northeastern margin of the Asiatic continent. This marginal area is as means fringed by trench-arc-bark-arc systems which constraint the formation of the transition zone from the continent to the ocean. Best known among the same system is a system composing of the Japan Trench-Nankai Trough,Japanese island Arcs, and the Sea of Japan (the East Sea). The East Sea as a whole marginal sea consists of at least three deep depression which are separated by the system of the underwater arises and rises as shown in Fig.1. In this way the Ulleung Basin (Tsushima Basin) appear in the same system as the Central Depression of Sea of Japan and the Yamato Deep Basin.

Based on this viewpoint the Ulleung basin is one of the major basins in the East Sea (Fig.1) which structure is believed to be subject of great help into the understanding of the formation of the East Sea. As widely known there are many number of speculative models which have been postulated for the decision of these problems (Kaseno, 1975;1980). Those models are usually classified into three group: (1) oceanization or crustal thinning,(2) entrapment of ocean basin, and (3) ocean floor spreading associated with relative continental drift.

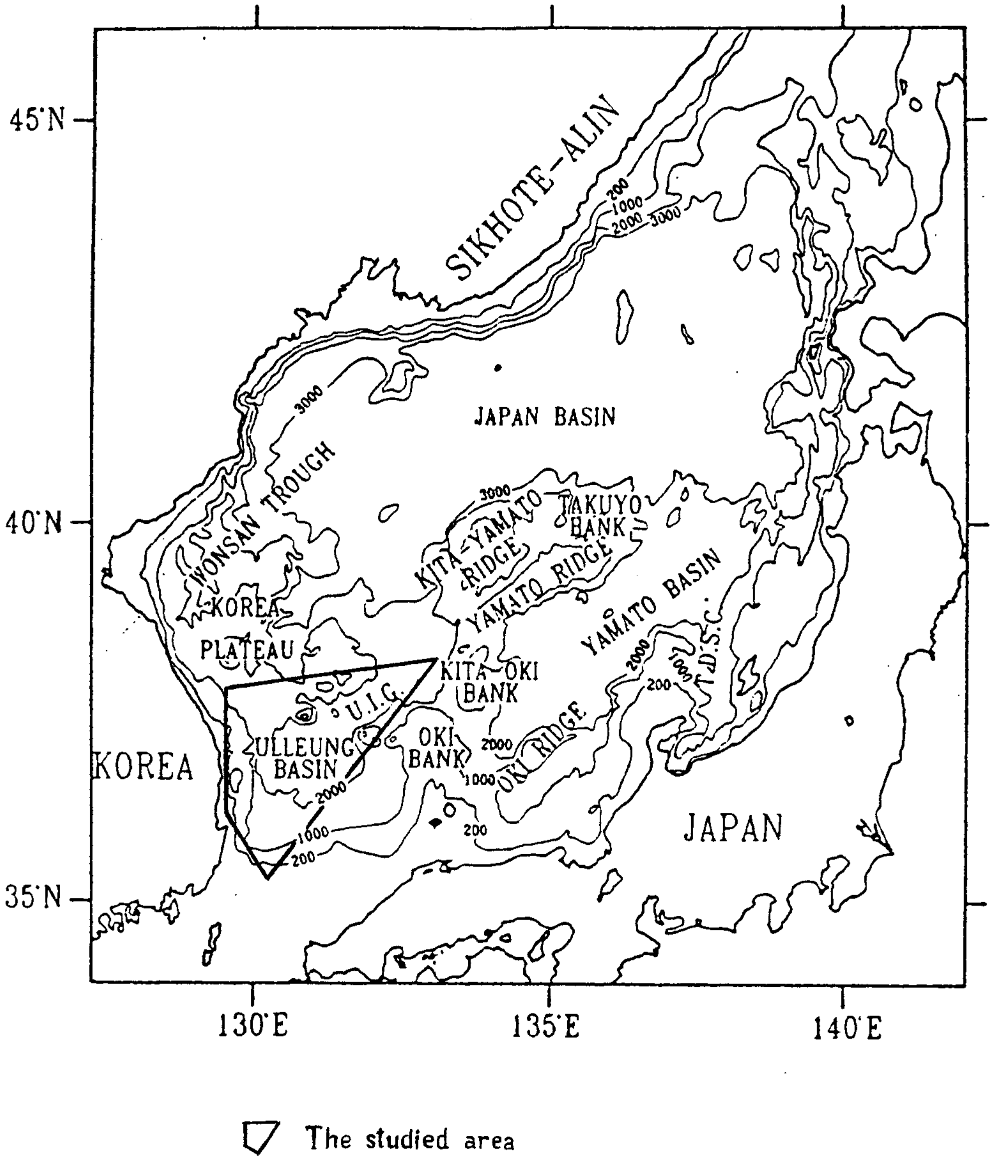


Fig. 1. Major physiographic features of the East Sea

However the first and second groups of those models are assumed to be disregarded because it is seem to account that those groups haven't and can't get up the crucial evidences on their realization. In this way "the opening models are the most popular but the ages and modes of opening are still in debate" (Koboyashi,1985; p.438).

It is need to point up that the paleomagnetic data are the main indicator of same opening process among available geophysical evidences. Of course the same confirmations of many investigators are perhaps not to be become true but the ignoring of those is also unrightly.

Based on opening models the fan-shape opening of the Ulleung Basin are predicted to its formation (Ishickawa and Torii,1988) or the normal spreading process have been developed here as well as it had suggested the East Sea as a whole (Hilde and Wageman,1974).

However, at any reasons the Ulleung basin are less studied with respect to other area of Japan Sea(East Sea) and this circumstances is not to be the favorable to decide some problems of seeking any mineral deposits on offshore of Korea as assumed above.

To these goals just past several years in the Ulleung basin area had been provided the widespread complete investigation which more results had gotten from seismic reflection survey by the Korea Petroleum Development Corporation (PEDCO). Besides it's reality if the common result of the all studies on offshore are well known and at total had the attempt to be explained by basic postulates of the tectonic plates. However there are many detailed features of this region which are no discussed in an alternative manners (E.Barg,1986,K.E.Lee, 1992). The principal disagreements which arise on comparable bases are the existence contrary to the tectonic plates and real geological proof.

The main of these discrepancies is as follow: all the results are based on the similarities of stratigraphic correlation and structural compositons between in partly southeastern Korea and northern Kyushu and Tsushima-Korea straits. Really it exist many of the features of the sedimentation cut which are similar. However as it is recognized by E.Inoue(1982) the existence of some questions which arise from those comparisons. Principal of them are the most than the possible variety of the times of the shift of the southwest Japanese island arc, and than it is found from comparison of the phases of tectonic moving which declared and confirmed by various investigators. Therefore the correlations between stratigraphic stratas of the Cretaceous rocks in the Gyeongsang basin in Korea and northern Kyushu outcrop the some problems and make the postulates of plate tectonics very obscurity(Inoue, 1982).

So forwards, there are a large contrast in Tertiary strata between both regions and "the geological structure of Tsushima strait is different from those of both the areas "(Inoue, 1982,p.98),and follow so as " In any case the geology of Tsushima and it's offshore area offers the key for understanding the tectonic history of these areas" (in that place above). In another side, the newest geophysical data been provided on Yamato Basin of eastern part of the Sea of Japan by Japanese scientists shows that there are the many problems to fit into the ideas of plate tectonics on the origin and evolution of this region(Isezaki,1986;Otofuji et. al.,1986).

According to those results the Yamato Basin have been more plausible occurred by mechanism of the stretching of the earth's crust due to rifting process which accompany with the uplift of hot mantle plums and the extension of environment on the basement level (Kuramoto,1991).

Of course, there are many another evidences that may think to apply the theory of plate tectonics to geohistory of the reviewed regions it need to make very carefully. In any case, it's not the strong systems of the proofs from which this theory flows out without obscures and it's very complete to understanding of the origin and evolution of the Ulleung Basin on its base.

For the part of increasing our understanding on this problem have been stood the goals of the two cooperation Korean-Russian cruises using R/V Morskoy Geophysics and R/V Prof.Gagarinsky which was provided in 1991, Aug.-Sept. and R/V Morskoy Geophysics was conducted in the Ulleung Basin and on offshore of the eastern coast of Korea in 1993,april-may.

CHAPTER 2

PURPOSE AND SIGNIFICANCE OF STUDY

CHAPTER 2. PURPOSE AND SIGNIFICANCE OF THE STUDY

2-1. PURPOSE

The main purpose of the study are defined by the seismic data results which have been got on offshore Korean Peninsula since 1966 when the first marine continuous reflection survey had conducted by Huntec Limited of Toronto,Canada(Huntec Ltd,1968).

The later the seismic study using reflection and refraction methods were wide spreading to put into the investigations of the sediment structure of the southwestern and southern parts of the Ulleung Basin(Schluter and Chun,1974). Besides the Korea Petroleum Development Corporation(PEDCO) seismic reflection survey had been made in central part of the Ulleung Basin been using the multichannel digital seismic profiling system(Lee,1992). Those last results were strongly to advance the understanding of the sediment structure in this area.

At last, nearby the reviewed region many geophysical data have been held by Japanese and other investigators using seismic, gravimetric, magnitometric and etc methods essentially before and during realising DSD Projects in terms of Leg 127 and Leg 128. Based on those data many interesting and promising ideas were discussed and summarized.

In this meaning before starting of the first Korea-Russian cruise the Ulleung Basin was formulated in terms of ocean crust as a back-arc spreading basin (Hilde and Wageman,1974) but with the most biggest thickness of the deposits and the crust than normal ocean area.

However in processing those prior studies there have been arisen many details of the structure which no fitted in the slender conceptions that it was drawn upon the plate tectonics. Main of them it was not understanding to the relations of the acoustic and geological basements of basin, age of origin and of extension, direct and stages of evolution and etc.

Furthemore,the Ulleung Basin as shown and remarked above is subject to study by the deep seismic sounding method because it's to adjoin to the Korean Peninsula and it is suggested to have many valuables clues to the entire into the formatted framework of the East Sea as whole.

On the bases of means above, Korean Ocean Research and Development Institute(KORDI) and Institute of Marine Geology and Geophysics of Far East Branch of Russia Academy of Sciences (FEBAS) had found the possibilities to tie up with the both side and put to test of mutual research cruise on the East sea region. The fundamental goals of this cooperative cruise was subject to study of the Earth's crust by refracted wave methods and to search the crucial distributions of the velocity properties along acoustic basement.

The other tasks were to be resolved consistently.

2-2. SIGNIFICANCE

Before it's need once more to back out to tectonic position of the Ulleung basin. This region is one of the principle parts of East Sea (Sea of Japan) area. If it is possible to compare only the bathymetric data and geophysical evidences there will be found the many differences with respect to the Japan deep basin and displayed some similarities with the Yamato basin.

Besides the Ulleung Basin is in drastic tectonic situation with respect to the Japan deep or Yamato basin as well as it is situated nearby to Korean Peninsula and both Tsushima-Korea straits and Kyushu on the southern-southwestern directions and the Korea Plateauon the northwestern because of all these structures are involved in term of continental crust (Fig. 2,3). Thus, the Ulleung basin are ensured of at all the patterns of transition zone between Asia Continent and Japanese Volcanic Arc in more then those northern vicinity areas manners are. By analyzing all evidences and experimental data on which the pronounced mechanism of the formation of the Sea of Japan (East Sea) based in term of plate tectonics it may represent a some principal their features as follow.

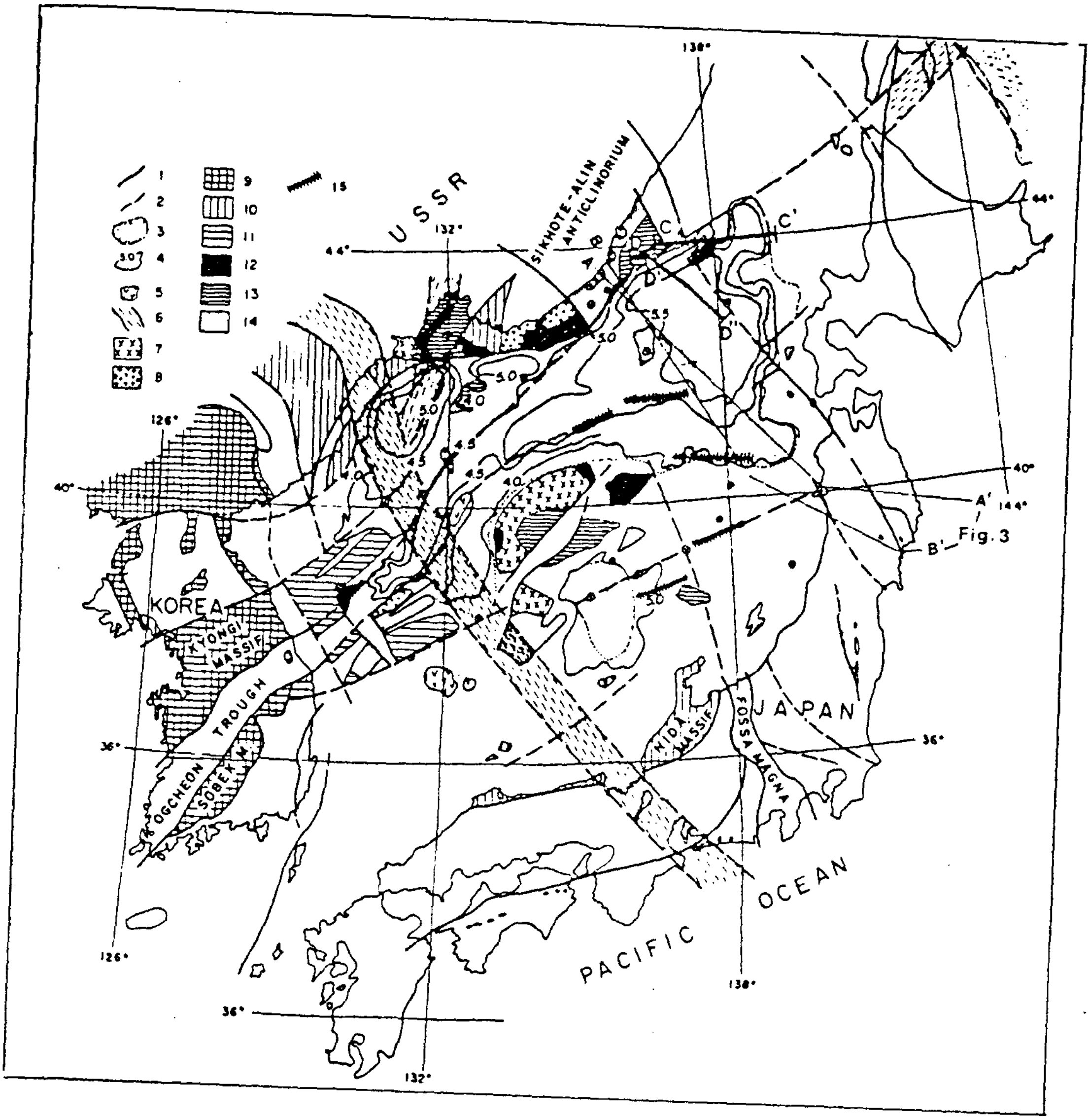
1. There are the weak possibilities to suggest that the magnetic lineations which are the common and the most strong evidences at the plate tectonics are really existence (Kuramoto, 1991) in term of several short system anomalies in area of Japan deep basin where these have been discovered. However there remain another areas of East Sea as well as the Yamato and the Ulleung basins where the same evidences are not yet discovered exactly.

2. The Japan deep basin is considered to be floored by normal oceanic crust that fitted on to form during sea floor spreading process. However the more details of the refraction study which were conducted by DEL-1985 Project(Kimura et.al.,1987) show that the Yamoto basin was estimated with abnormally thick ocean crust that in summarizing with "less obvious magnetic linealions and late seamount activity all indicate that normal spreading mechanism like mid-oceanic ridges was not likely to be responsible for the formation of the Yamato basin"(Kuramato, 1991,p15). In this case, it is very important to study the Ulleung basin in terms of the whole scale, of the crust.

3. As known the crucial role of the acoustic basement among

Fig. 2. Structural map of the Japan Sea showing the major deep-seated fault systems, tectonic trends, distribution, of major rock types and surface relief of the "suboceanic crust". Distribution of Archean and Proterozoic rocks on land is also indicated. Note the continuation of major tectonic trends on land over the entire Japan Sea region , and control of the basic structure of the sea by major tectonic zones. Compiled mainly from Park(1960), Yanshin(1966), Rikitake et al.(1968), Melankholina and Kovylin(1976), Minato et al.(1979), Solov'vev (1978), Tuezov(1978), Bersenev and Levi-kov(1979), Gnibidenko (1979), ovylin (1979)), Smislov et al.(1979),and Choi et al.(1982,1984).

Key: 1. Major deep-seated fault; 2. Infered extension of the major deep-seated fault; 3. Area with "suboceanic crust" ("basaltic" layer); 4. Depth of contour of the surface of "suboceanic crust" from the sea level in km; 5.Tertiary and Quaternary volcanic island or submarine rise; 6. Active seismic zone with deep earthquake foci(300 to 450 km); 7. Late Paleozoic granitic rock; 8. Late Cretaceous granitic rock; 9. Archean on land; 10. Proterozoic and possible Proterozoic on land; 11. Archean and Proterozoic metamorphic and granitic rock; 12. Permian and Paleozoic marine sediment; 13. Upper Cretaceous and Paleogene sediment; 15. Proposed spreading center based on magnetic anomalies (Isezaki,1975). (Constructed by Choi,1983)



USSR
SIKHOTE-ALIN ANTICLINORIUM
KOREA
KYONGI MASSIF
OGCHEON TROUGH
SOBEK M.
JAPAN
HIDA MASSIF
FOSSA MAGNA
PACIFIC OCEAN
Fig.3

Fig. 2.

Fig. 3. Tectonic design of relationship of marine and continental structures of East Sea and its frame.

The folded continental and marine structures of the East Sea frame:
1-Archean; 2-Pre-Cembrian; 3-Early Paleozoic; 4-Paleozoic; 5- Mezozoic; 6-Cenozoic, 7-Mezozoic-Cenozoic superposed depressions and troughs; 8-intraplatform depressions, 9-volcanic superposed zones.
The large structures of East Sea depression:
10-eart crust of suboceanic type; 11-continental earth crust (shelf and continental slope) in the eastern part of sea; 12-continental earth crust(island shelf and slope) in the western part of East sea; 13-subcontinental earth crust of the Korean zone; 14-subcontinental earth crust in the eastern part of sea; 15-relics of Pre-Cembrian continental earth crust; 16-relics of Paleozoic continental earth crust; 17-deep fault zones of continental structures of frame; 18-deep fault zones near the Primorye and Korea beachs; 19-deep fault zones of deep sea regions; 20-regions of established connection between marine and continental structures; 21-thickness of earth crust; 22-heat flow values; 10**-6 cal.*cm**2/s.
A number in the circle:
1-foreshore anticlinorium of Sikhote-Aline; 2-main anticlinorium of Sikhote-Alin; 3-main synclinorium of Sikhote-Alin; 4-Alchan trough; 5-Hankay massif; 6-Daubikhin trough; 7-Sandagou marginal depression; 8-Suyfun through; 9,10-Suputin trough; 11- Suchan -Sudzikhin anticlinorium; 12-Tumangan folded zone; 13-Kvanmo massif (K-Kamtchak massif); 14-Ammokan trough; 15-Khasan-Rivon trough; 16-Khannim massif; 17-Pkhemam trough; 18-Keaungy massif; 19- Ogcheon trough; 20-Sobecmassif; 21-piedmont Scushima trough of Sacav geosyncline; 22-Khida belt; 23-Khida massif; 24-Tuvou folded zone; 25,26- Tugouku folded zone; 27-Rakeau folded zone; 28-Sambagava folded zone; 29-Titibu folded zone; 30-Simanto folded zone; 31-Nakamuro geosyncline; 32 -Kanto trough; 33,34-Kitakami folded zone; 35-Khidaka main belt; 36- West-Sakhalin synclinorium; 37-East-Sakhalin block zone; 38-Peter Great bay; 39-shelf and continental slope of Korea; 40-Near-Korean zone; 41-shelf and slope of the Japan Islands and Sakhalin Island; 42-Bogorov Rise; 43-central deep depression; 44-ridges of Yamato Rise; 45-deep-water part of Khonsu depression; 46-Foreshore falt; 47-South Sikhote-Alin fault; 48-Shore geosuture of Sikhote-Alin; 49-Median fault; 50-Fossa Magna fault zone.

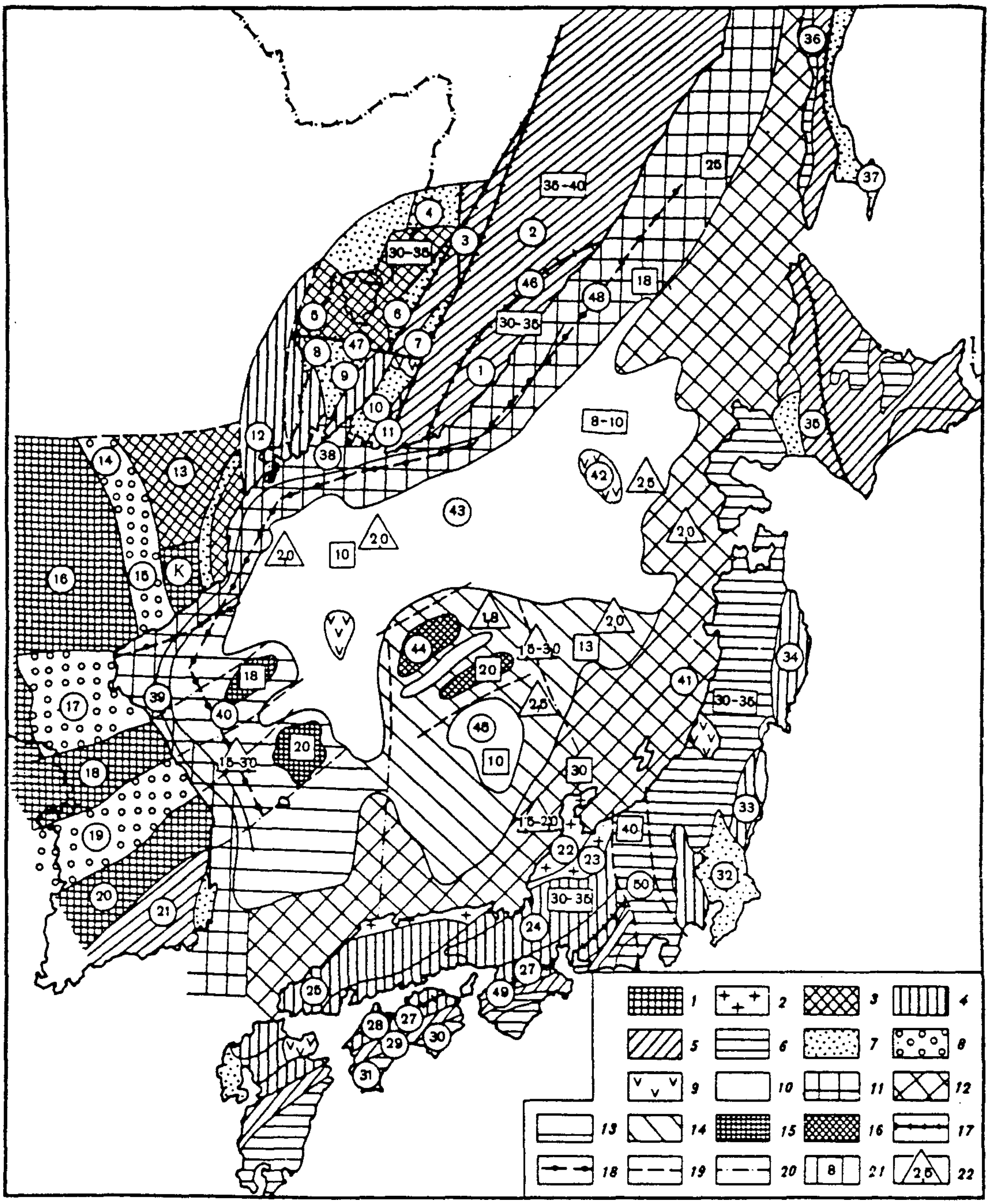


Fig. 3.

searching evidences of the spreading mechanism have been emphasized. Thus, reaching our knowledge to the true nature of the acoustic basement are of sharply significance. Provided that last time on the Ulleung basin the seismic reflected waves survey by multi-channel methods of PEDCO have also arisen the big difficulties with those in view of the interpretation in terms of acoustic basement. It is strong variety on the squares of area, in the depth, or in the velocity and in the patterns. So, it is still any of the reasons do not view the Ulleung basin as the sea-floor spreading area. And so, in this case those significant ideas must be stood upon the basement to plan before the research cooperative cruise and to define the main goals. The reviewed study aimed at investigation of the crustal structure of Ulleung basin.The emphasis was given to acquisition, processing, and interpretation of deep refraction and the accompanied reflection data from an experiment planned and conducted in the summer of 1991 by the joint research program of Korea and Russia. Our final goals have been to present the crustal structure of the Ulleung basin in a whole scale and to estimate the ways of origin and evolution of the East Sea as whole structure.

CHAPTER 3

DATA ACQUISION

AND

PROCESSING PROCEDURE

CHAPTER 3. DATA ACQUISITION AND PROCESSING PROCEDURE

At the beginning of 1991, KORDI and IMG&G FEBAS agreed on cooperation of geophysical works to investigate the deep crustal structure of the Ulleung Basin by using Russian research vessels employed OBS's(Ocean Bottom Seismometer) and large capacity air-gun.

The OBS,which detects and records seismic wave fields at the relatively quiet ocean floor, have been well suited into along range of two line layout which was directed along (Profile 1) and transverse (Profile 2) the major axis of structure of the Ulleung Basin(Fig.4). Such configuration pattern was supported to be adequate for evaluation of the crustal structure studied area. To constrain the sedimentary structure of the Ulleung Basin, and also to control the conditions of initiations of the seismic wave propagation on the sea-floor continuous seismic profiling with the use of a high frequency sparker was also adopted.

3-1.THE EMPLOYED EQUIPMENTS AND TECHNIQUES OF STUDY

3-1-1. The Techniques

A. Refraction Wave Survey

The experiments of recording refracted waves propagation was conducted by using the OBS's which have been distributed along geophysical cross over lines with interval about 12 - 15 nautical miles.

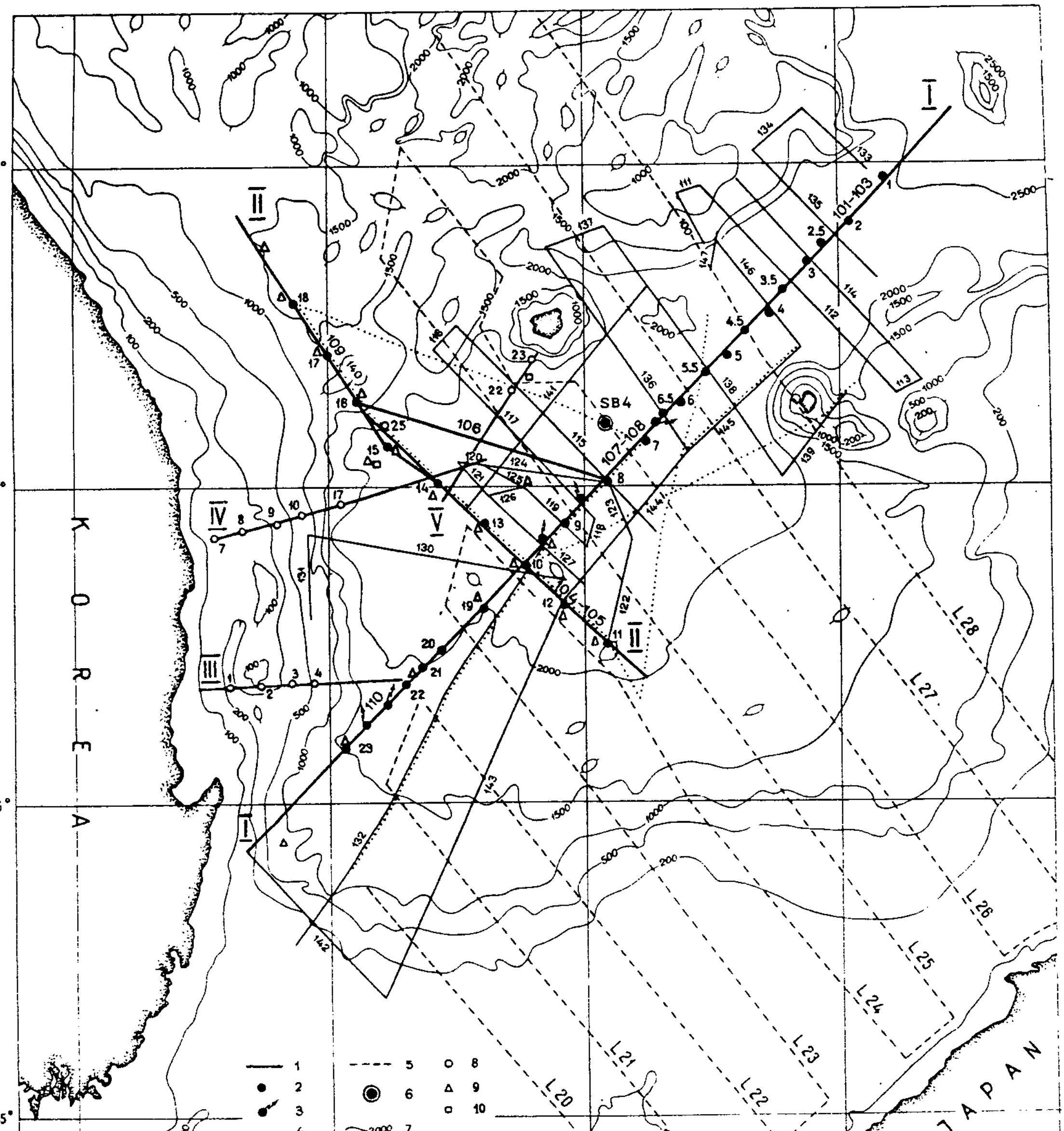


Fig. 4. Configuration and setting of the experiment.

Key: 1-Surveys lines; 2-position of OBSs; 3-position of SB; 4-Surveys lines Schpr (single-channel profiling of reflection wave); 5 Surveys lines Schpr (Honza,1978); 6 Sono-buoy (Honza et al.,1978); 7-Isobaths in meters; 8 Surveys lines of magnetic data; 9 Heat flow stations; 10-Magnitovariation stations.

Total extending with 180 and 110 nautical miles were realized on the both profiles respectively and about 30 OBS'station have been situated.

Each OBS consists of a seismic receiver and a registration unit cased into a steel cylindrical container. The vertical electro dynamic seismic receiver as NS-3 type is mounted in a joint pendant, providing vertical orientation of the axis independently of the container position on the subbottom. The own frequency of the seismic receiver is 3.0 - 4.0 Hz while the degree of damping and transmission coefficient are 0.55 - 0.70 Vs/m, respectively.

The registration unit consists of the band drawing mechanism with electronic plates of the station and block of autonomous quartz clocks, which provide time-service in terms of the absolute world time-date regime. The band drawing mechanism is constructed by one-motor scheme, whose leading assembly is an electric motor with stable current of IDR - type. The magnetic tape type is H4406 - 12 which moves at velocity of 0,39 mm/s. The capacity of magnetic cassette is usually 350 m, providing continuous registration of seismic oscillations at a station for 10 days. Number of motor turns is kept strictly stable with the help of an automatic regulation scheme. An electronic engine is powered by 6 battery with less than 1,5 mA current.

Registration is made through an eight channel block of magnetic heads. The following information is recorded on magnetic tape: seismic signal on two sensitivity levels with spread of 30 dB; enveloping of hydroacoustic channel; time code (on two tracks); accompanying signal(pilot signal);minute pulses. The frequency range of registered seismic signal is 2 - 25 Hz. Total geodynamic range of seismic tracking is 70 dB. The level of dynamic overlapping between sensitive and coarse (basic)channel is 10 dB. The amplification noise,reduced to the enter is less than 0,25 mkv eff.,that allows to record useful signals with the shift about 15 Angstrom/sec.

30 OBS's were dyploid at the sea-floor as pointed above along two profiles. Profile I starts at the northeast rim,running between islands,Ulleung-do and Dok-do and terminates at the southwest rim of the Ulleung Basin. Profile 11. perpendicular to Profile 1, was planned such that the recorded wave fields would provide crustal seismic anisotropy information if it's possible(Fig.4). The profiles were composed of 10 seismic lines, each of them had 5 OBS's at interval of 10 or 20 km. After the " Morskoy Geophisic" deployed 4 or 5 OBS's at predetermined locations along a straight seismic line, the "Prof. Gagarinsky" traced the seismic line shooting an air-gun to generate seismic waves. Two air-gun with 60 and 30 liter capacity were used alternatively at 4 and 2 minutes fire-repetition rate. As the ship speed of the "Prof. Gagarinsky" was 5.5 to 6.5 knots the fire-repetition rates of 4 and 2 minutes correspondent to 600-700 and 300-350 meters respectively. The frequencies of seismic wave signature generated from both air-guns were maximum at 18 and 30 Hz respectively.

B. Continuous Profiling Survey

Simultaneously with air-gun shooting the conventional continuous profiling using the sparker was conducted along the whole seismic track lines constituting main profiles 1 and 11 and orthogonal lines studied by the "Prof. Gagarinsky". This last profiling work was expected to yield the fine subbottom sedimentary structure. If it would be to subject to study by same weak source as sparker it assumes to explore the basement surface, which in turn served to constrain the analysis of OBS's data. The sparker with 12 - 14 K Joule capacity and the floating towering hydrostreamer about 50 m of useful length have been used as seismic source and receiver respectively. The both were designed and manufactured by IMG&G. As the frequency band of the emitted seismic signals from sparker is approximately 90 - 150 Hz, resolution of profiling is not expected to exceed 15 meter and evidently not possible to exceed the big subbottom penetration. The investigation depth below the sea floor reached commonly not more than 1.0 - 1.5 sec in two-way travel time(TWT scale) in sedimentary stratum sequences corresponding to 0.5 - 1.2 km in depth. Thus at least the uppermost and partly the middle cut of the sedimentary column was fully investigated. The profiling data was recorded on an analog graphic recorder and to compare them with other same data was possible only up cross-section level. However, the total line length fulfilled by profiling reached 1490 nautical miles and those data are seriously to be helped to the just enough understanding sedimentary structures of the Ulleung Basin.

3-1-2. THE EQUIPMENT

A. Single Channel Seismic Profiling System

1).Sparker

Energy	: 12 -0 14 K Joules
No. electrodes	: 7 - 9
Operating Electricity	: 380/220 volts
High Electricity	: 6 - 8 Kilovolts
Frequency of wavelet	: more than 60 Hz
Repetition Rate	: 9 seconds

2). Hydrophone, single channel towed streamer

Total length	: 250 - 300 meters
Length of Active Part	: 50 meters

No. Elements : more than 32

3). Graphic Recorder

Recording Paper : Electrochemical type

Recording Length ; Without delay - 3 seconds, With delay technique using the total time more than 20 seconds

4). Digital Recording Equipment

A/D Converter : 10 bits

Sampling Rate : 2 K Hz

Word Length : 1.5 bytes

Trace Length : 3 seconds

Trace Memory : 9,000 Bytes

Magnetic Tape Drive

Tape : 2,400 ft reel type

Recording Density : 800 Bytes/inch

Long Recording Period : 9 Hr

B. Deep Refraction Survey System

SYSTEM USED IN 1991,aug.

1). Ocean Bottom Seismometer

Receiver : Vertical channel only, Electrodynamic Type

Degree of Damping: 0.55 - 0.70

Transmission Coefficient: 24 Vs/m

Recorder : Analog Type

Magnetic Tape : Type H4406 - 12

Revolving Rate	: 0,39 mm/sec
Maximum Duration	: 10 days
No. Channel	: 4
Registration Unit	
Seismic Tracking	: 70 dB
Amp. Noise	: less than 0,25 m KV eff.
Mooring Type	: Tied to surface buoy by tailrape system

2). Air Gun

Volume	: 30 (1830 cubed inch) liters 60 (3660 cubed inch) liters
Frequency of Wavelet	: 12 - 18 Hz
Repetition Rate	: 2 - 4 min.

3) Air Compressor

Type	: Electrical 380 volt/ 20 kW
Power/Volume	: 15 liter/Min per one, 12.000 MPa
No.complect	: 4

4) Others

Navigation	: Loran/Transit Satellite Nav.System

THE SYSYTEM USED IN 1993,apr.-may

The refraction wave field study was made by the equipment set including the emission and receiver sets. The emission of seismic pulses is made by air guns, which have the following parameters:

- volume of working chamber - 30 liters (1830 inch**3);
- pressure of compressed air - 150 kPa;
- amplitude of the first pressure wave

at the distance 1 m - 300 kPa

- frequency range of emission spectrum - 7-30 Hz;
- period of the first pulsation - 0.16 s;

The reception and registration of seismic signals was made by the ocean bottom stations, which was designed in the Laboratory of Seismic Study Methods of IMGG and produced in Special Design Office (Yuzno -Sakhalinsk).

As a receiver the electrodynamic seismic receivers SV-10 for vertical and SH-10 for horizontal components were used. The receivers were arrange on the gimbals for vertical and horizontal orientations irrespective of OBS bottom state.

Seismic oscillation registration was made in analog form on the standard magnetic tape cassette MK-60 by the 4-channel magnitograf of type "%-b". For the expanding of OBS technical possibilities the registration of several channels was simultaneously performed on each of magnetic tracks with the different parameters of amplitude and pulse-frequency modulation. For the increasing of dynamic range the information channel record was made on the two channels with the different amplifications and dynamic span of 6 dB. With information record the auxiliary information including the code time in minutes-hours-days, synchronizing frequency and shot moment pulse was recorded on the magnetic tape. For the decreasing of magnetic tape consumption during the time from OBS installation to the beginning of shooting the delay mechanism was used. The delay time relative to the starting moment of quartz clock was controlled in the range of 0-24 hours with the step 2 hours.

The seismic information was recorded on the magnetic tape in the mode of pulse-frequency modulation for the elimination of mutual effects between the channels and various electromagnetic pickups. The quartz clock starting,its synchronizing with the shot moment and the determination of time deviation was made with the ship borne synchronizer 47-37.

The OBS installation and lift was made by the tailrape system. The OBS main parameters is following:

- natural oscillation frequency	10 Hz;
- working temperature range	5-30 C;
- minimum signal value for signal/noise ratio of 10 dB	3.5*10**-6 v;
- maximum signal value	5*10** -3 v;
- dynamic range	52 dB;
- relative time deviation of reference quartz oscillator	1*10**-6 s;
- maximum code time	72 hours;
- maximum sea depth	6,000 m;
- total weight	36 kg;

The digitizing of seismic information was made with IBM PC/AT, in which A/D Converter was placed. With this computer and the digital magnetic recorder of type CM 5309 the digital seismic information was recorded on the magnetic type. The sampling rate was 250 Hz, the record format - I2. The seismic traces as a record section were represented by the printer EPSON FX1050. The programs for set of representation allowed to change the parameters of amplification, filtration and also the vertical and horizontal scales in the wide diapasons.

C. Electromagnetic Research

The digital measuring equipment for geomagnetic research (DMEFGR) was designed and developed by the laboratory of geomagnetic research for magnetic variation. In usage the equipment had been improved and become the reliable means now for the automatic measuring of electromagnetic field variation onshore as well as offshore.

DMEFGR consist of two module: the overboard module - the independent digit station (IDS) and the onboard module - the digit input-output device (DIOD). The IDS is used for recording the total field vector, for digit representing its value and for long term storage. In IDS operating the magnetic measuring transformer of toroid type sends signal to the magnetometer. Then the signal from the decipherer comes to the controller,which represents the information as 16-bits word. One board can store 8192 words. Five additional boards can be connected to the controller. In this case total memory increases to 49152 two-byte words. Three information channel can be connected to the controller as well for recording the other physical parameters of the marine medium or for measuring the electromagnetic vector components. It's also possible to send digital information from the controller to the padiobuoy and then to the vessel in the real time.

The IDS should be place in watertight container. The container specifications depends upon the sea depth usage of the module. Measurement range not more than 65535 nT

Systematic error	2.0 nT
Reading error	1.0 nT
Space orientation measurement error	1.0 nT
Magnetometer voltage	+13 v
Electronic circuit voltage	+ 5 v

The digit input-output device (DIOD) can be connected to outer devices for information input and display, such as analog devices, microcomputer, digital display. The DIOD circuit is designed on fixed logic, providing its high reliability, and equipped with display for checking the input information in accordance to address. The DIOD allows also reception of information on telemetric channel. The research works were conducted with the modified spread of Fonariev's [Trophimov, Fonariev,1972) which allows to measure the medium impedance by synchronic measuring the total magnetic variation vector at the surface and at the different depths. The spread consists of two buoys, connected by a 50-100 m long rope.

One of the buoy is fixed by an anchor. The other buoy carries a chain of DIODs in such a way, that the lowest reaches the limit pressure depth for the container. The apparent bottom resistance were determined as the ratio spectrum of variations of the module of the total magnetic field vector at the surface,To(w), and at the sea depth, Th(w);(sometimes at the bottom).

$$Ra=0.2*T*\left|\frac{W - 1.0}{0.2*/*!*h}\right|^{2}$$

The transfer function W were used as the ratio To(w)/Th(w) and it have been found by the spectral analysis procedure [2]. For this purpose the initial series with the length of more than 24 hours have been centered and filtered in order to abolish trends and to suppress daily field variation.

D. Geothermal Measurements

D.1 Method and technique

Heat Flow (HF) measurements are produced by original IMGG equipment providing directly measurements of temperature gradient in subbottom sediments and definition of thermo-conductivity of deposit sample been using piston-core operations.

The stations of HF was placed along seismic Lines I and II; distance between neighbor stations fitted just closely about 10-15 nautical miles. To measure the temperature gradient is used the original technique - cable two channel quartz thermo-gradientometer which was set on probe intended for extraction of sediment piston-cores. This technique was constructed in IMGG FEBAS RAS and been subject to allow the definition of the absolute temperature and the temperature gradient in situ accompanying this operation by selecting the sediment column (about 2,5 meter) to follow geophysical analysis. The parameters of those equipments are as follows:

- kind of sensor-quartz resonator is 5 mHz and sensibility fit up closely 200 Hz/ C;
- spread of measuring temperatures is 0 -60 C;
- absolute error of measurements of temperature is +0,03 C;
- distance between neighbor sensors along probe is 100cm;
- sensitivity on the temperature changes is not less than 5*10**(-4) K;
- time of frequency instability is not more than 0,1Hz/h;
- working angle of thermo-gradientometer is about +15 ;
- maximum of researching depth is about 6000 meters;
- total working weight is not less than 200 kg;

The geophysical cable for both the descent and ascent and also for transmission of the experimental data are used. Its diameter is 1cm and tensile strength is not less than 6000 kg;

The temperatures and their gradients are calculated by standard technique which have been using the frequencies caused by both absolute(a) and differential(d) channels:

$$T = (F - A)/ K$$

$$gradT =[F - F - (1 - K / K)*(F - F)]/ l * K + gradT \qquad (1)$$

where : l - distance between sensors which attribute the frequency-temperature functional coefficients K ;

F - frequencies corresponding to absolute and differential channels respectively while these are situating to measure in water(w) and sediment(s) environments;

A - value of frequency of absolute channel for T= 0 C

gradT - gradient of temperature upon sea bottom level;

The differences of the mechanical and physical properties of subbottom sediments and the time vary to the investigative process product the necessary conditions to search the value of the frequency (F),which are corresponded with temperature equilibrium between probe and environment of sediments.

The next formula (2) have been used to decide this problem:

$$F = F + (F - F)*exp(-m*t) \qquad (2)$$

where :

F ,F - measurable and initial frequencies;

m - coefficient which depends on the size of sensor and its transfer heat - possibility as the response on temperature change inner environment.

The formula(2) is good approximation with respect to cooling and reheating processes of sensors since 5 minutes after penetration of equipments. Values F have been calculated by the least square method and after this operation it had inserted in formula(1).

The time length of measurements usually consists of 25-30 minutes after sea bottom penetration of our thermo-gradientometer. In this case if the full time of the temperature equilibrium is just close to 60 minutes the instrumental errors of the measurements may have to be around 5-10%.

The example of the thermogradient curve are displayed in Fig.1. The thermoconductivity measuring are conducted by well-known "needle-probe" method. In this way the measuring step fit up 20 cm along the column of sediment piston-core. The value of thermoconductivity which are used to calculation of the Heat Flow was to be equal to one that have been defined on basic of middle values been presented by aryphmetic average of all values of thermocoductivities along this core samples between two sensors(7 measurements). The middle values of standard deviation used by Student's criterion operation have been calculated and have been provided the correction to remove the differences of temperatures between sea bottom and laboratory data.

The errors of the Heat Flow are determined in terms of the sum of measuring errors of the geothermal gradient and standard deviations of thermoconductivity.

3-2. PROCESSING PROCEDURE

The processing procedure are presented by standard to OBS-data techniques operation. The first step of the data processing aimed at producing preliminary record sections. After OBS was retrieved the seismic trace data recorded in magnetic reel tape in analog form were digitized. Than these bandpass were filtered the data using a FIR (finite impulse response) filter with 0-12,5 Hz band which appears to enhance the signal to noise ratio. Before producing basic seismic record sections the multiplication factor x/20 km was used to correct for amplitude decay due to increasing source-to-receiver offset. The OBS data sections were linear moveout(LMO) corrected using the reduction velocity of 7.0 km/s which is assumed to be a typical velocity of the lower crust (layer3). But in any ways the OBS data section were presented in usual form in terms of standard set of seismotraces. After that set of Travel Time Curves(TTC) along every OBS-Line were constructed in view of the straight-reverse system of TTC on basic of which the seismic cross-section are drawn up by using the time-fields technique. On the basis of those preliminary results of the structure of the crust the modeling stage come up to realize solving of direct kinematic and only small volume dynamic tasks,according to SEIS83-Program(Cerveny and Pcencik,1983;Hirata and Shinjo, 1986) on two-dimension space. The modeling procedure are finished when residual between theoretical and experimental time are fit not more than 0,02sec. After that all models combine in terms of resulting cross-section data and are to be interpretation stage.

In case of another methods the description of their features will be presented during overview of the results of these investigations.

CHAPTER 4

BATHYMETRY

AND

SEDIMENT COVER

CHAPTER 4. BATHYMETRY AND SEDIMENT COVER

4-1. BATHYMETRIC PATTERNS

The East Sea (Sea of Japan) comprises three deep basins as shown in Fig.1: central deep depression of the Sea of Japan, Ulleung and Yamato basins which are separated by ridges and banks (Yamato Ridge, Korea Plateau, Kita-Oki bank, Oki bank, and Oki Ridge). The Ulleung basin is outlined as basin with middle depth about 2000 m and width about 150 km. It is separated by the Ulleung Interplain Gap (U.I.G.) of the two sub basins, one is on the northeast and the other is on the southwest, respectively (Chough, 1983).

The northeastern Ulleung sub basin is bordered by steep slope of the Korean Plateau, Yamato Ridge (including Kita-Yamato Trough), Kita-Oki and Kita Banks. It is likely that the southwestern extension of the sub basin is progressively uplifted toward the WSW direction. However, this rising is prevented by the Ulleung Interplain Gap (UIG) which displaying in the elevation of sea floor are represented a small subbottom arise caused of the buried volcanic swells (Tough, 1983). The elevation of the subbottom mounds are not more than 100 m. From the control outline of the isobath-line such as "2100" or from the other bathymetric maps such as "2200"m (Fig.5), the continuous extending of the sub basin is toward the WSW direction, possibly.

As it is sense above the main path of the Ulleung basin are situated on the south from line Ulleung-Dok Islands. It is seen that the gently progressive mount of sea floor toward the south, southwest and southeast directions. This sub basin is wide area and is bordered by continental shelves of Korea Peninsula and Southern Honshu and the

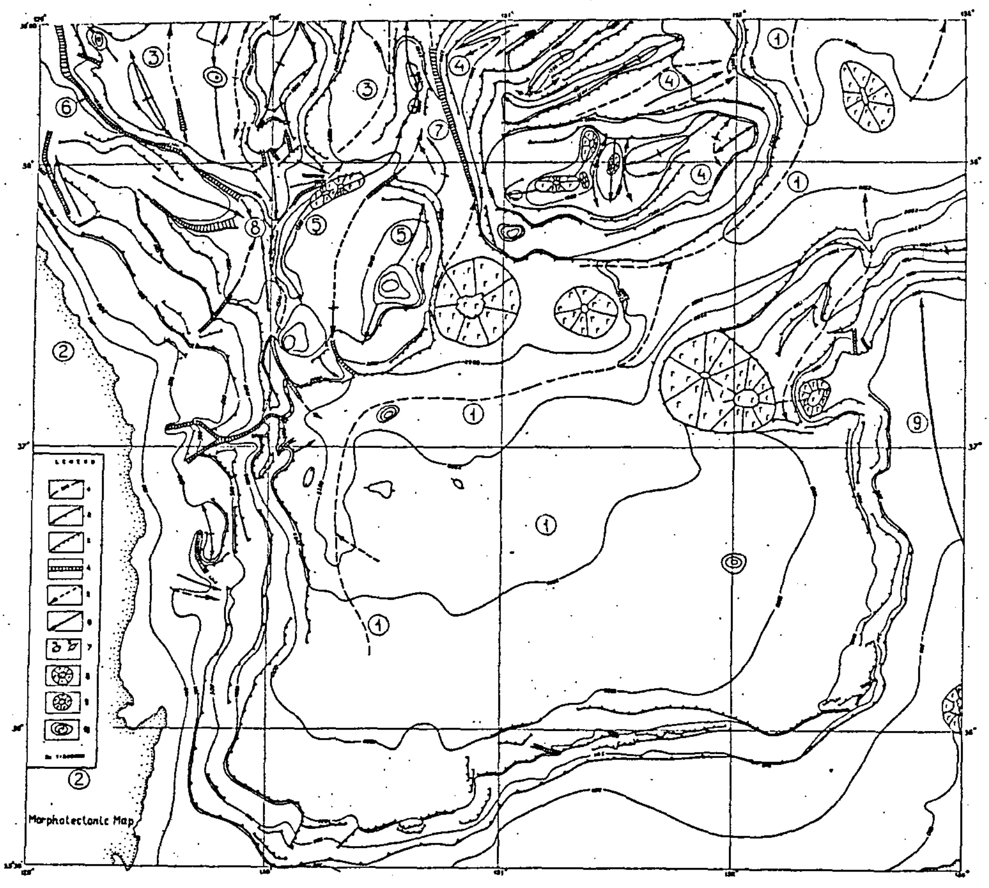


Fig. 5. Morphotectonic Map of Southern part of East Sea.

Scale 1:500,000

Authors V.P. Semakin and A.S. Svarichevsky.

Key: 1-Isolines of the "top" surface (the numbers - depth,m); 2- Brows of flexures and tectonic scarps; 3-Foots of flexures and tectonic scarps; 4-Bottom of narrow grabens and V-form depressions; 5-Axises of relative morphotectonic rises; 6-Axises of relative morphotectonic depressions; 7-Local rises (a) and depressions (b); 8-Above-water- underwater volcans; 9-Underwater volcanic structures; 10-Isolated underwater mountaines and eminences of unknown origin.

Marked by the numbers; 1-Ulleung basin; 2-Korea penincula rise ; (3-8)-the complicated underwater rise of the Korea plateau; 3-Wonsan plateau rise; 4-Ulleung plateau; 5-rise to the west from Ulleung island; 6- Wonsan trough; 7-Ulleung trough; 8-Mikho plateu; 9-Oki rise.

steep slope of the Oki-Bank structures. Besides, it seems that the greatest role played in the formation of this sub basin is both of the structures of the Tsushima-Korea straits.

Both of the Korean Peninsula and the southern Honshu shelves are represented by the narrow strips of about 25-30 km width. The seafloor of the shelves is rather smooth, transition zones to slope in many cases are gentle on the uppermost and reverse steep on the middle part of the continental slope. Wherever environment and inner areas of these shelves zones are developed great number of the inner rises, broad mounds and valleys and fault-thrusting structures which of all are exhibited by the smoothness of sea floor. It seems very important to understand as the Ulleung basin structure in the sense of the northwest and north-northeast boundaries are constructed. As told above the deep subbasin of the Ulleung basin are bordered by trip of the Korean Plateau. The Korean Plateau consists of a north branch-Wonsan Rise (near 39 latitude) and a south branch- the Ulleung Rise(near 38 latitude). Both of those branches are separated by the deep narrow channel so-called as the Ulleung Trough. The Wonsan Rise is about 100 km wide and 250 km longs and trends toward the northeast. The Ulleung Rise is wider than 150 km and 200 km long and trends east. The Ulleung trough trends east-northeast. All the structures bordered are on the northeast and sided by narrow deepest bathymetric channel into NW-SE trends. This latest are situated between the main Arises and Ridges of this path of the East Sea. The surface manifestation of the buried powerful fault zone. is possible.

4-2. THE ACTUAL MORPHOLOGIC STRUCTURE

The "morphotectonics" of water area shows the tectonic movements and its produced structure forms ,immediately mapped to the bottom topography. Moreover, it is assumed that the structure forms of morphotectonic dislocations is not purely tectonic so long as they are more or lesss leveled by the sedimentary processes. Among the large variety of morphotectonic dislocations, we distinguish two main type: relative "rises" and relative "depressions", which may be considered as "positive" and "negative" morphotectonic dislocations, respectively. Rises and depressions may be plicated, disjunctive or injective (or be represented by a combination of these type), simple or complex, and of
various sizes, i.e. various "orders" or "ranks".

The rather detailed bathymetric map drawn by Svarichevsky A.S. (Pacific Oceanology Institute, Vladivostok) was used for the construction of the Morphotectonic Map of Southern part of the East Sea (Fig.5).

Morphotectonic Map is developed in the main by the geomorphological characters. As a "structure" (reference) surface the "top" surface of sea bottom mapped by the absolute depth isolines (relative to present day ocean level) was used. This surface is polygenetic and polychronic as the acoustic basement, but just it allows to map the morphotectonic dislocations with the corresponding forms occurred in the forms of sea bottom.

On the Map the brows and foots of flexures and tectonic scarps (to separate the flexures and tectonic scarps, i.e. morphotectonic faults, seem to be impossible by the bathymetric data at this stage) are drawn by the geomorphological characters; the axis of relative morphotectonic rises and depressions and local rises and depressions are drawn; the above-water -underwater and underwater structures and isolated underwater mountains and eminencies of unestablished origin are shown. Morphotectonic structure units of different orders appeared in the form of bottom topography were likely to be made at the Pliocene-Quaternary in the main.

In the limits of region under study the main morphotectonic structure units of conventionally first order (Fig.5) is as follows: the Ulleung basin, the Korean Peninsula Rise, the complicated underwater rise named the Korean Plateau and (9) the Oki-Bank Rise.

In the Scuth (1) the Ulleung Basin is limited by the relative rise coincided in space with the Korean straits. The Tsushima Island is a member of this rise, which may be conventionally named in this connection as the Tsushima Rise. In the west of the southern part of the Ulleung Basin border on the complicated above-water morphotectonic (neotectonic) Korean Peninsula Rise. In the north and north-west of the Ulleung basin border on the Korean Plateau and in the East it is limited by the (9) Oki-Bank Ris.

The Ulleung Basin is parted by the above rises with the sets of tectonic scarps, which are the morphologic image of young morphotectonic faults. The southern part of the Ulleung Basin represented as an assymmetrical depression, the axis zone of which is shifted for the West and North. The depression is extended for latitudal direction and is a shape of isometric with a broad and gentle southern flank. To the north of underwater volcanic swell of Dok-Ulleung Isl. and (see above as UIG), the Ulleung Basin (sub basin) extends for north-western direction as a morphotectonic grabbed, in the north, it broaden towards the deep basin of the East Sea.

In the northern and north-western parts of the region of the Ulleung Basin to the north of Ulleung Island latitude that there is the Korean Plateau Rise, consist of three complicated rises (Fig.5): the Wonsan Plateau, the Ulleung Plateau and the Rise situated to the west of Ulleung Island.

The Wonsan Plateau is limited to the west by the Wonsan Trough and to the east it is separated from the Ulleung Plateau by the Ulleung Trough. The Rise situated to the west of Ulleung Island is limited in the west by the narrow depression conventionally named as Much Trough. The above Rise and also the Wonsan Plateau (3) is complicated by the submeridional rises and depression of higher order. In the limits of the Ulleung Plateau (4), the being complicated rises and depressions of higher order are extended in the main to the north-eastern direction.

The Oki-Bank Rise situated in the eastern part of region is under study. It is extended to the meridian direction limiting to the east the southern part Ulleung Basin.

In the limits of region under study, the underwater volcanic structures are plainly distinguished in some places especially to south-east of Ulleung basin.

It must be noted the morphotectonic rises and depressions are in general coincids with the sedimentary structure elements established by the seismic data, i.e., they are inherited tectonic elements in this part of the East sea.

4-3. SEDIMENT COVER

The result of the sediment cover under study comprises two kinds of experimental data. The prior investigations include the material of seismic single channel profiling provided by Japanese and American geophysics (Ludwig et. all., 1975; Hones et. all., 1979; Hirata et. all.,1987) Also, the multichannel reflection seismic survey in the central part of the Ulleung Basin conducted by PEDCO. Second, all of the data were completed by a new single channel seismic survey which have been conducted in mutual cruise by KORDI and IMG&G and the original evidences by the refraction method survey. Most of the analyzed completeness in the Ease Sea area actually the description of cover structure has been made by S.I.Kuramoto(1991) and K.E.Lee (1992). According to those results our interpretation are based on the main features of their lithology stratigraphy subdivisions (from top to bottom) as follows.

4-3-1. UNIT-1

The unit-1 composes with two sublayers, upper of those unit 1-1 presents the youngest geological strata which consists of mud, turbidites , clay, silty clays interleaved by a few ash layers.

The interval velocity is not more than about 1.52 km/s and characterizes not consolidated deposits. Besides, the transition zone from sea-water to subbottom deposits is not sharp and takes place on gentle manners. In the central part and its western side of the northern subbasin of the Ulleung Basin, the submarine Deep Sea Fan deposits have been established in htee term of likely Toyama Deep Sea Fan in the Tamato Basin. Those deposits show clear deep sea channel natual level in the term of submarine mounds and over flowed structure (Fig 6. Lne 112, 114, 135, 146). The deposits of chennel origin are distributed along the basin and around the Ulleung-do as well as shown by the Figure 4-5 of K.E.Lee (1992, p.79) and (fig. 6). The interval of Unit 1-1 is characterized by interlayered fine stratigraphic strata which have been described in the term of the strong horizontal and vertical stratiphycative layers. Between the boundaries are often local unconformity and angle unconformity that have been caused by the significant hiatus. It presents the breaks of the several time interval of depositions or errosion processes. Those features are well recognized on

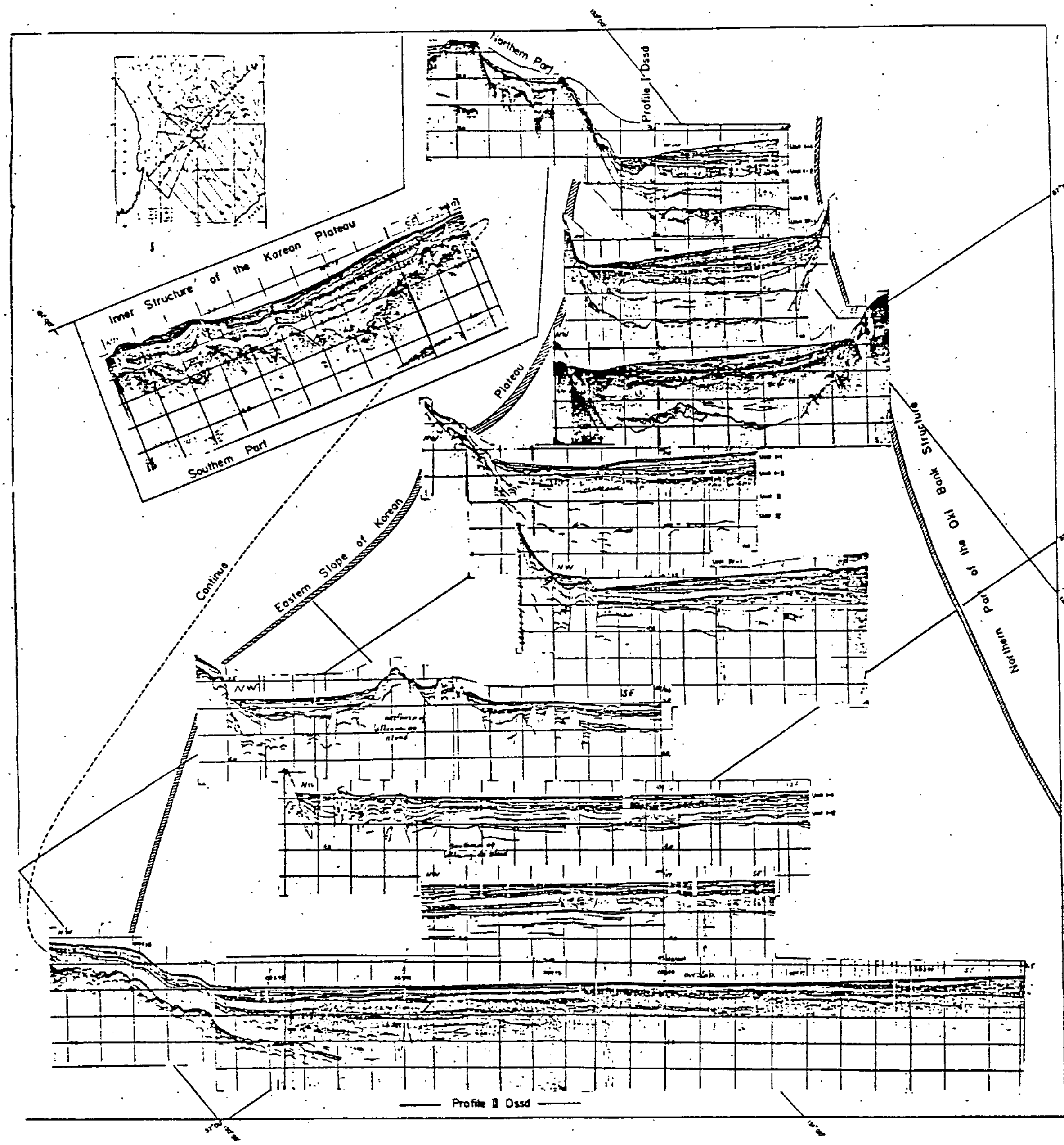


Fig. 6. The block-scheme of single-channel seismogram,b3en provided on perpendicularly to Line 1 of DSSd-OBS; the fixed position related to intersections of their with Line 1; (a)-decreasing of fig.2 and be showed dark region - the area of expanding actual turbidity deposits.

the single channel seismic data which using the high-frequencies records. One of those stratigraphic hiatus are well established by thin transparent layer which the angular unconformity in the middle part of the Unit-1 and separates this strata on the two stratigraphic sequences.

In this case, there is a record over the periods of time in the stratigraphic column with different geohistory. It's considerably that the same features of Unit 1-1 strongly pointed tha the southern edge of the Ulleung Basin which contacts with the trending of the Tsushima-Korean straits are established in the term of a wide (about 10-15 km) relative deep (about 500m) channel. It is not doubt that it is the surface image of the Tsushima-Goto fracture Zone. It seems that all coverings on the continental slope on the offshore area of eastern Korea have been filled by redepositted material under mass flow. The same process may be predicted from prior study which had been conducted by U.Schcluter and W.Chun (Shcluter and Chun,1974) on the northeastern off Pohang area.

At all, the distribution of the most youngest deposits of the Ulleung Basin can be estimated based a the piston-core data accompaying with heat flow measurements. The realizing of those are as follows.

A. NOVOCENE SEDIMENTS OF THE ULLEUNG BASIN

Sediments under study have been selected at the various physiographic zones: foot of continental slope and central part of the Ulleung Basin (Fig.4).

Sediment structures of each sediment piston-core were described after visual analysis. Grain size analysis was made by using the combination of sieve and pipette methods for some narrow intervals of cores which consist of sediments, presumably, differing by composition.

Water-content and bulk density were determined by the weight method, and calcium carbonate content - by the reaction with HCl.

A.1. VISUAL DESCRIPTION AND SEDIMENTARY MATERIAL

All cores may be divided to 3 groups according to the visual sediment characteristics and sediment structure types.

The first group is the cores of sites 16 and 17, which are mainly represented by the muddy sediments of dark-gray color (Fig.7). These sediments with a faint odor of hydrogen sulfide are slightly bioturbated all over the cores and have the dark stains (hydrator-lite separation) which especially intensive in the core range of 25- 70 sm.

The second group is the cores of sites 9 and 10, which are represented by more coarse-grained, dense, viscous and monotonous olivine-gray mud. The sediments are bioturbated and have an intensive spotted structure lower than 25 ms under the sea floor.

The third group is the cores of sites 1-8 and 11-14 (Fig.7). These sediments have a large range of colors and hues: from whitish-blue to dark-green and dark-gray. Variously pronounced, layered structures are displayed in this cores. A laminated structure is mainly determined by the color change and established below 100 ms subbottom along the vertical core profiles. Thus 3-5 distinctly laminated sediment units of 10-23 ms in thickness is resolved by a set of light, light-gray and dark laminae of 2-20 ms in thickness in the cores of sites 8, 12 and others. The relatively coarse-grained mud of light-colored laminae reacts with HCl, a main bulk be dissolving and grain of white color be saving. Another type of laminated structure is related with pumice-rich, gravel-size, gray sediments below depth of 100 cm; the upper interlayer is fixed in the range of 100-120 cm, the

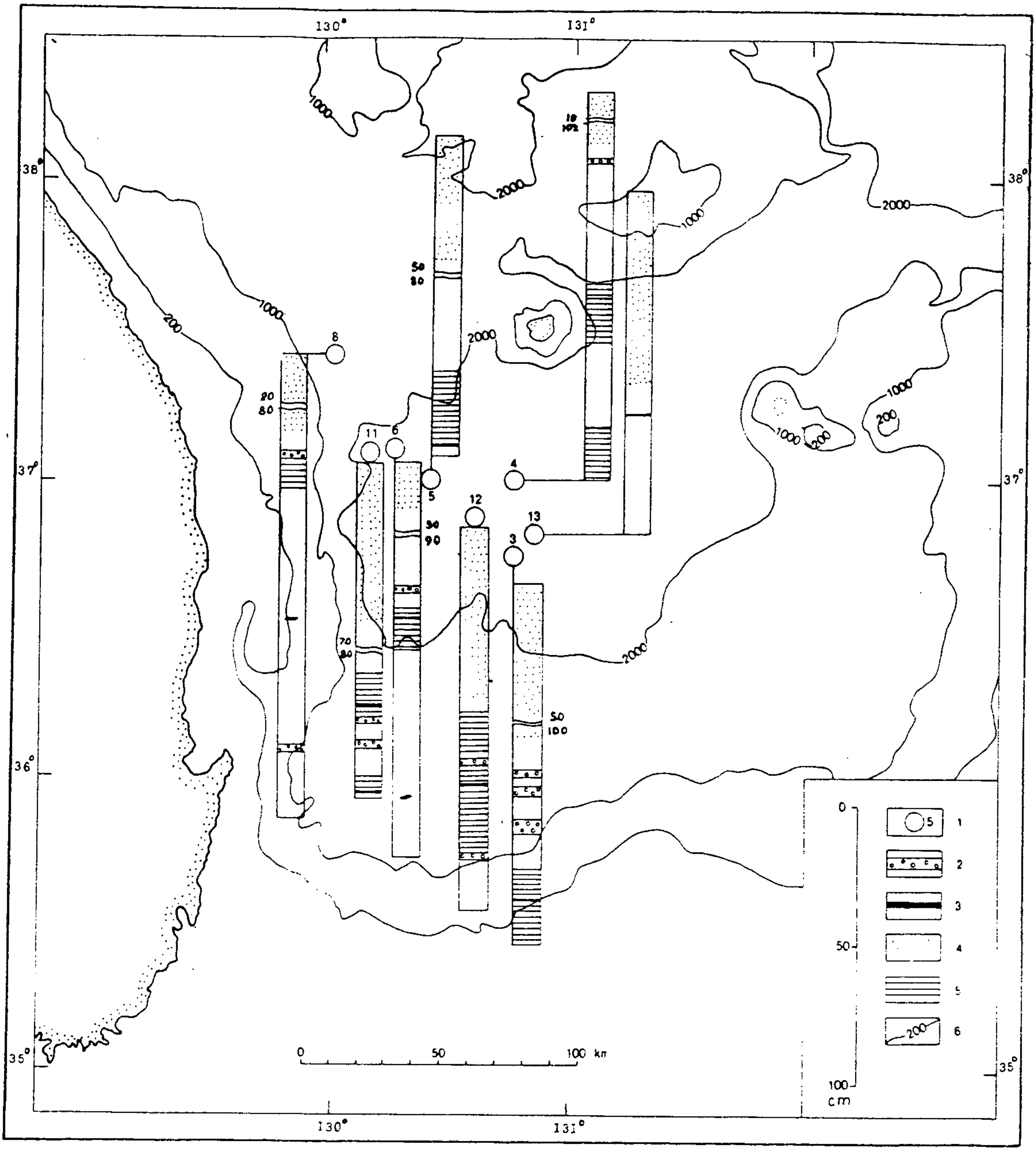


Fig. 7. Core locations and sedimentary structures visible to the eye within cores.

Key: 1-number of site; 2-pumice layers; 3-ash layers; 4-structureless sediments; 5-distinctly laminated sediments; 6-isobath.

lower one 165-200 cm. Thin interlayers (2-5 mm) composed with volcanic glass of sand-silt size have a sharp contact with underlying sediments and are diffusive at the roof.

A.2. Sediment texture

Sediments under study consist of silt and clay-sized material and is characterized by polymodal distribution of grain-size fractions. Content of sand-size material varies from 0.5% to 21%, the maximum content be determining for the gray interlayer (site 11, 149-149.5 cm interval). The gravel-size (Md is up to 2.5 phi) light-gray pumice material occurs both in scattering form (sites 13,14 and others) and in the form of 1.5-2.0 cm thick interlayers (Fig.).

Sediments with Md 5.1-5.9 phi (silt content is 60-65%) and Md 7.0-7.6 phi(clay content is 55-65%), which may be named silt and clay mud, respectively, are dominated in the basin. More fine (Md 8 phi) and more coarse (Md 4.4-4.7 phi) sediments are formed by thin interlayers (2-5 mm) in the sites 8, 5, 11, 12 and others.

A.3. THE VERTICAL DISTRIBUTION OF SEDIMENT MATERIAL

Unstratified sediments are composed of homogeneous mud. Thus the content of silt and clay are 18-39% and 57-67%, respectively, Md varies slightly from 7.6 phi in upper part (5 ms depth) to 7.3 phi at a depth of 185 ms in the sediments of site 16. Sediments are poorly sorted and polymodal: maximum mode is 9.2-9.7 phi and mode 2-5.1-7.2 phi. The mode 2 became finer due to increasing of clay-size material in sediments (67%).

Sediments of site 9 are more coarse than sediments described above, with Md 5.65-6.54 phi (content of silt is 54-59%) which became finer along the core from top to bottom. These sediments are also polymodal, maximum mode reaches the coarse silt size (4.2 phi) and mode 2 is 9.2-10 phi.

The core of site 12(Fig.8) is represented by the poorly sorted sediments with Md 5.2-6.8 phi. Depending on the silt-clay content relation, the maximum mode characterizes either clay size (9.6-10 phi) or silt size (5.2-5.5 phi). The most fine muds with Md 6.7-6.8 phi complete the laminated rhythm in 120-150 cm interval of the vertical profile (Fig.8).

Core of site 8 is the most interesting by the variety of its sediments. The upper part of vertical profile (0-90 ms) is composed of poorly sorted monotonous deposits with Md 5.54 phi (content of silt is 59-60%),maximum mode is 4.16 phi (coarse silt), and mode 2 is 8-10 phi. In the 90-106 ms interval, where the pumice interlayer is the more coarse and well sorted sediments with Md 4.5 phi, maximum mode is 4.16 phi, predominate. Median coarsing of these sediments is caused by decreasing of clay content. The lower part of core (up to 220 ms) is composed of mud with Md 5.2-5.5 phi: the maximum silt mode becomes finer up to 5.4-5.7 phi due to decreasing of coarse silt particles. The general tendency of variation of granulometric composition is remained in the cores of sites 3 and 5. The upper part of cores (up to 80-90 ms) is composed of fine (Md 7.5-8.0 phi) and relatively monotonous sediments. The content of silt material increase lower in the vertical profile. These silt muds consist of the pumice interlayer (site 3, the range of 115-118 ms) and scattering pebble (site 5). The interlayers, which are composed mainly of volcanic glass with coarse silt size (Md 4.7 phi), are resolved at a depth of 140-166 ms (Fig.8); the well sorting of sediments is caused by a significant dominance of two silt fractions in their composition (maximum mode is

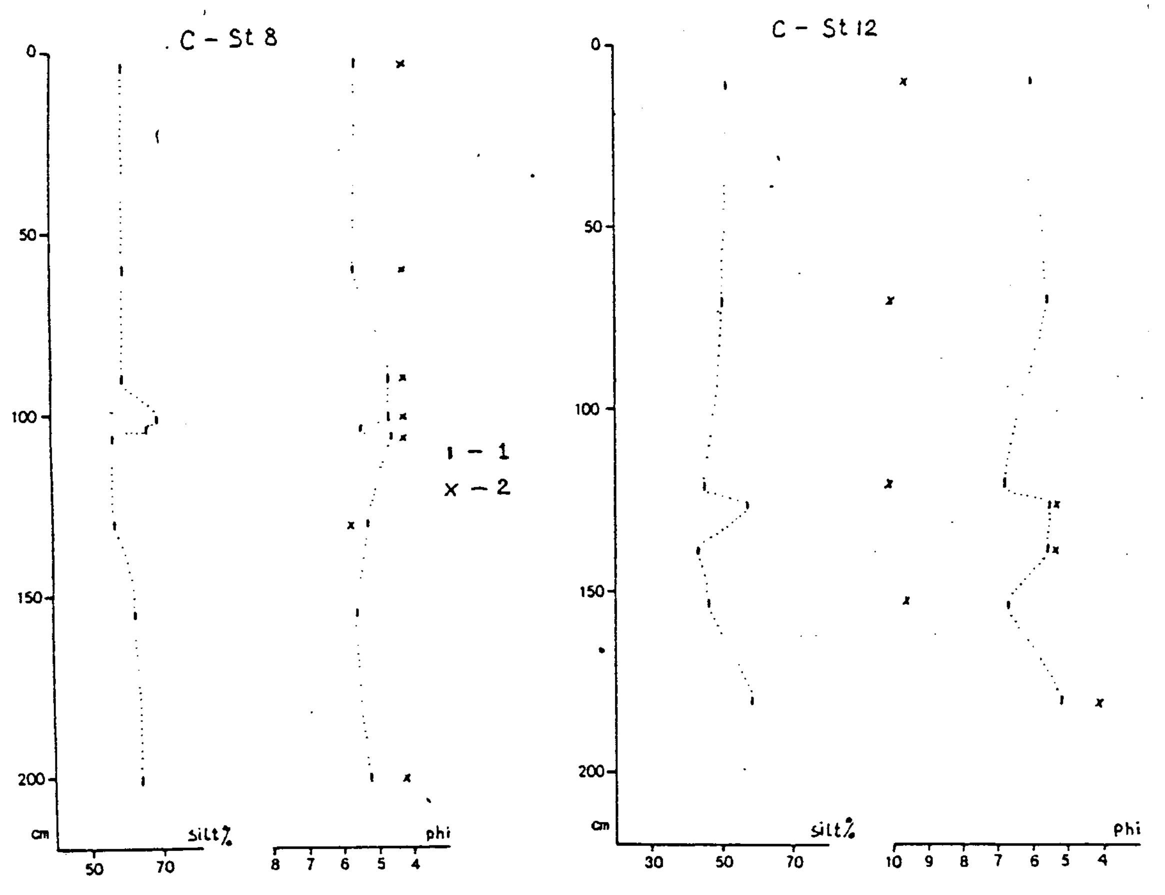


Fig. 8. Log and measured grain-size parameters of sediments of East Sea.

Key: 1-median (Md); 2-isobath.

4.2 phi and mode 2- 5.3 phi).

A.4. AREA DISTRIBUTION OF SEDIMENTS

As a results of the sediments study the area spreading of gravel and sand-silt interlayers may be considered. The volcanic glass interlayers (ash interlayers) are well correlated across some sites: the upper one (range of 120-160 ms) in sites 5, 6, 12 and lower one (range 180-200 ms) in sites 4, 11 (Fig.8).

In the opinion of investigators (Lee et al., 1981) the volcanic pumice interfere at a depth of about 200 cm is formed 9300 years ago. Accepting this estimation the average velocity of turbidite accumulation may be 30-40 cm/1000 yr.

In the basin a pumice source is the Ulleung Island, but limited spatial spreading of pumice fragments is controlled by an effect of cold water masses (Lee et al., 1981; Kim and Kim, 1983). Coinciding spread areals of the pumice and ash material may, in general, be considered as a region of turbidity flow relaxation descending from the islands into the basin (in the vicinity of site 8 and others).

A.5. PHYSICAL PROPERTIES OF SEDIMENTS

Politic and fine silt muds are light, bulk density varies from 1.21 to 1.30 g/cm**3; water saturation is 60-70%. The coarse silt sediments are sufficiently more heavy, the bulk density is 1.46-1.62 g/cm**3, water saturation 42-50%, the maximum values are determined in the individual samples.

A.6. FINAL REMARKS

The character of sediment structures, the variation of sediment composition over the area and vertical profile of cores allow us to do some preliminary conclusions about the conditions of sedimentation as follow.

1. In central part of the Ulleung Basin the accumulation of sediments occurred as a result of action of turbidity flows, which supply inequigranular material into the basin. The completion of intensive turbidite sedimentation is fixed by the upper clearly laminated unit (at a depth of about 100 ms). The monotonous pelite muds in upper cores part may be considered as the layer E of classic turbidite (Bouma,m1962). But in the most deep sea part of basin (sites 3 and 5) these sediments acquire the attributes of homogenates (Kastens, Cito, 1981) or nefeloidites (Murdmaa, 1986).

2. The monotonous unstratified sediments of continental slope foot was possibly formed as a result of both an action of weak turbidity flows with the low concentration of silt-sand material and a background (hemipelagic) sedimentation.

At all the total thick of the Unit 1 don't fit up more than 600 m sec TwT(two-way-time) and increases in area of the south toward direction from Ulleung-do as well as 650-700 m sec Twt thick. Besides established stratigraphic hiatus is very significant that onlap the Unit 1 are recognized wherever on the slope of the Korean Plateau. In many cases the lowest part of this unit (Unit 1-2) have the weak migrating wave form. This wave form image having wavelengths up to 3-5 km and amplitudes not more 50 m suggests that series of sediment waves migrate over a horizontal surface, which is here the regional disconformity. Hereto the several reflectors in uppermost part of Unit-1 may have the origin of the Bottom Simulating Reflector (BSR) and may be marked as well as the OPAL-A/ OPAL-CT transition or the Gas Hydrate Horizons (Atlas, 1979; Kuramoto,1991).

In any cases if those suggesting reflectors are really the BSR they can be described by isotherm of 50 degree C' and it products the regular heat flow model (Kuramoto,1991) of the earth's crust of the East Sea.

In conclusion of this item its need to show a map presenting the area distribution of configuration pattern for Unit-1 on the Ulleung Basin as whole (Fig.9).

There are very important features from those distribution pattern: the maximum of thickness of the Unit-1 are established along edge parts of basin and minimum of one - on its central part. Its not doubt that the same features caused by distance from sources land of deposits and there is not another alternative reasons.

4-3-2. UNIT - 11,

The Unit-11 is characterized as a weak or "transparent" interval except the separate boundary in the uppermost part of the strata between Unit-1 and Unit-11. This boundary is closely strong disconformity and have possible been continued on the whole area of the investigations.

The inner structure of Unit-11 is not clear because it is possible in the seismic fields to seek the seldom weak reflectors in the middle part of Unit-cut and near on the slope of the Korean Plateau. Also the some reflectors are established in area of submarine volcanoes where their morphology are the steep bending. It's possible that same behavior caused by the injection of intrusive or aborted volcano mounds. In those places it's evidently establishing that this Unit-11 may have in any case about two subdivision the lowermost of which practically transparent for acoustic waves. These features continuous up to the slope and the summit of Korean Plateua. In this way the upper

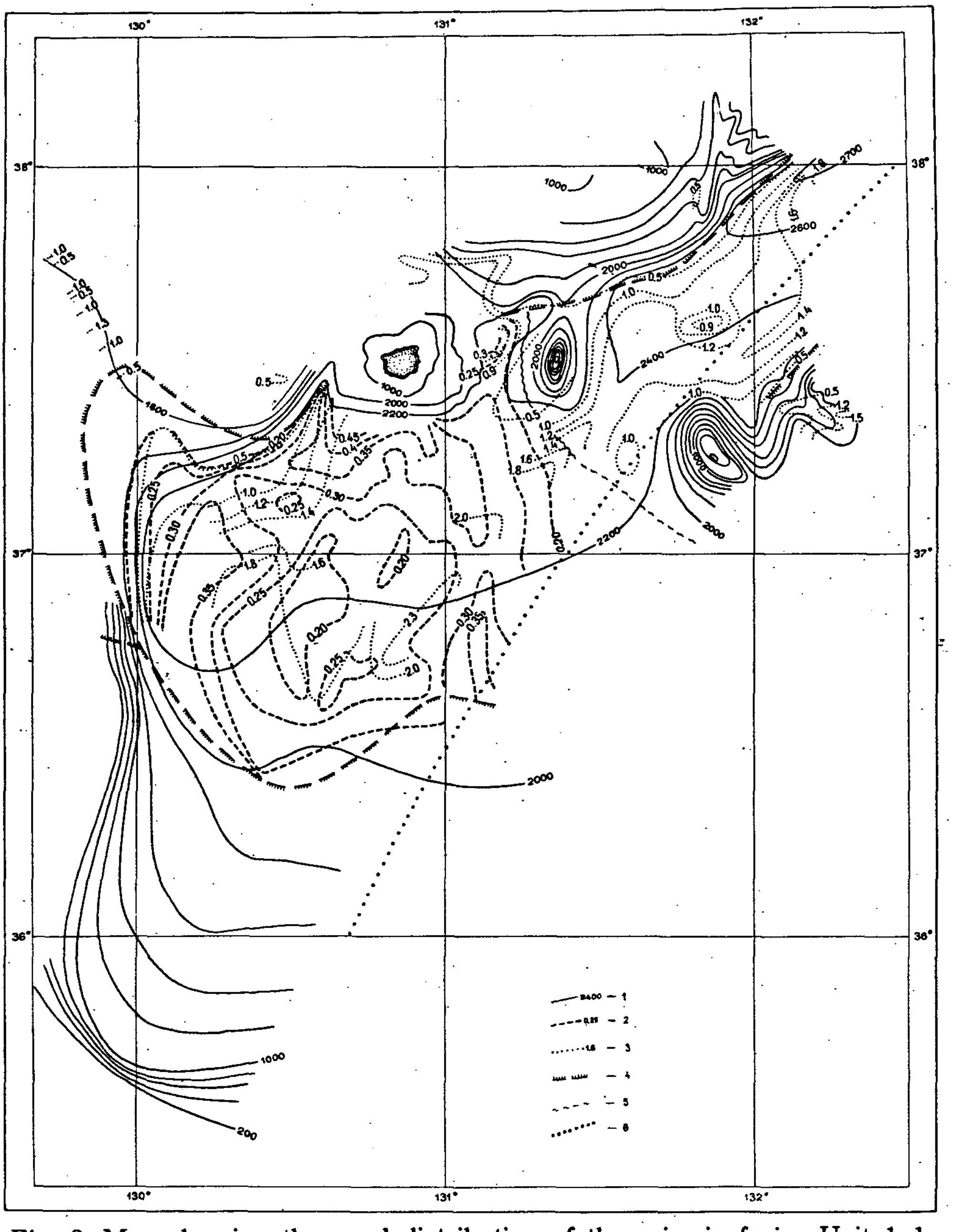


Fig. 9. Map showing the areal distribution of the seismic facies Unit 1-1 and, the acoustic basement and bathymetry (in meters) in the Ulleung Basin.

Key: 1-isobath; 2-thickness of Unit 1-1 in TwT,s; 3-depth of occurence of acoustic basement(km); 4-interface of type acoustic basement; 5-change of the sedimentary cover section type (Unit I -Unit III); 6-axis of spreading zone according (Hilde and Wageman, 1973).

subdivision exactly onlaps on those slopes. It's more that the lower part of this unit onlap to the acoustic basement (Fig. 6, line DSSd) filling and flattening to the juts and caves of this specula surface.

In another cases this unit is characterized by erosion truncation (Fig.6 ,Line 130,146),and onlap by its lower (bottom) boundary conjoin to top boundary of the Unit-111. Essentially it is pointed upon the western part of the basin nearby on the continental slope of the Korean Peninsula when this unit contacts with bottom of the Unit 1-2 (Lee,1992;Line 6).Besides,as it might be found the buried channel which geometrics have been established by Line 6 of multichannel seismic survey just enough on the south direction from Ulleung-do (Lee, 1992). According to the comparison both submarine channels in the top of Unit-1 and Unit-11 it's need to point out their significances for the geohistoric evolution of this Basin.

It seems that strata of Unit-11 is indicated of the thick section of marine shale indebted by thin sandstone and silt stone beds. The chaotic facie is interpreted as a slide or a slump deposits (Lee, 1992). However, the sediment wedge of the southern part of the Ulleung Basin near on the continental slope of the Kyushu Island and the Oki-Bank structure indicates the influx of the terrigenious sediments.

There are many types of onlap, downlap and toplap forms of contractions of lower boundaries, essentially on the northern part of Basin and on the slope of the Korean Plateau where the same deposit process flattened the relief of the acoustic basement. In another side it's always established the hot contact, volcanic apron forms and buried volcanics mounds in the vicinity of the Ulleung-do and Dok-do and in the inner part of some Fault Zones.

Besides there are the wide development of the piercement and nonpiercement types of shale domes on the Korean Plateau structures (Fig.6) and so the wide development of the narrow canyons are raised that is filling up the inner parts of the caves on basement essentially on the northern part of the Korean (Ulleung) Plateau area.

The total thick of Unit-11 may have to size more than 0.7-0.8 sec TwT thicks. The maximum of the thicks were established on the southwestern part of the studied area (Lee, 1992) where this Basin contacts with structure of the Tsushima-Korea straits. In total the Unit-11 is characterized by the interval velocity range from 1.7 km/s to 2.20 km/s. The ages of this unit may have to define as the Late Miocene - Pliocene of age. At all both the Unit-1 and Unit-11 are represented as just closely similarly to those of the whole East Sea (Sea of Japan)) and characterized by the well correlation between all Wells of ODP Leg 127 and Leg 128. This correlation bases on the spreading process explanations for the origin and opening of this marginal Basin.

4-3-3. UNIT-111

The Unit-11 are disconformitlly underlayered by the strata of Unit -111. In the many cases the boundary between these sequences was not recognized on the base of using of the single channel seismic data because it is not possible to reach up the needed depths if the investigation is ensured by small power of sparker source only. The using other more powerful sources for the seismic single channel profiling or multichannel seismic survey allow to research the boundary between Unit-111 and Unit-11 in the term of the strong well stratified reflectors strata. Unit-111 includes in many cases so-called reverse polarity reflectors (Carotta, 1986; Kuramoto, 1992) which is an indicator of the variability of physical properties associated with changing of the lithologic contrast between the upper and the lowest media. The Unit-111 interval is well studied here by the multichannel seismic survey and by refraction study.

The Unit-111 may have to be separated on the three sequences which are discribed different images and long interval velocities (3.17 - 5.10) km/s. Usually into deep depression of the marginal basin the top of Unit 111-1 or Unit 111 -2 was recognized in the term of the surface of the acoustic basement or the roof of the oceanic transition layer 2. It is always assumed when the seismic research work haven't the necessary depths of exploration.

May be the first among the investigators who named here the Unit-111 as acoustic basement were Ludwig W. et. al(1975).They suggested that the acoustic basement under the Japan Sea coincides to "green tuff" whose P - wave velocity (more 3,5 km/s). On opinion of many authors it is just closely to roof of the normal oceanic layer 2.

In footnotes, these authors have emphasized that the layer attributing the P-velocity about 3.5 km/s have the determining significance to understand the origin and evolution of deep basins of the Sea of Japan. They suggested that if a spreading process was a true it must precede to deposits which cover upon the acoustic basement cited above and the most young sequence as means as those model of distribution of an inner structure signify the accumulation on the stable sea bottom.

Whereas the corollary from ODD-Project (Leg 127 and Leg 128) are found to be established that rocks of this acoustic basement as whole strata are presented by series of vertical (pillar-form) basalt sills and volcano flows which intercalated into sedemental strata. In this way the uppermost of magnetic sequence combines the dolerits and lava flows alike with the arc tholeiites. There are fine sediment stratums inner of this magnetic seguence which contain the deepest benthonic foraminifers. The lowermost and the more ancient magnetic units include the sills and lava flows which compose from back-arc tholeiites and alkali-basalts interbedding by shallow sea deposits of sandstones and silt stones of the Early-Miocene age.

In this case (hole 797) the alkali-basalt volcanism is strongly resembles that in the continental rift - zones (Exploring...,1990). In same time the results of multichannel seismic survey provided on the Ulleung Basin Area by PEDKO (Lee, 1992) may have to mind that acoustic basement sequence which under layers the cover sediment are strongly variable on whole basin as in the term of velocity as well as the deep-seats. The same features of this strata are well coincided to total scheme of evolution of volcanic process on the Ulleung Basin area.

After an integrated analysis of all available data there reformulated in the term of the map showing the area distribution of main configuration patterns (Fig. 9) for acoustic basement on the Ulleung Basin. This map constructed on basis of reflection method was updated by the refraction results. The actual submission about these features may get from the review of the seismic cross-section of Line 1 and 11 (Fig. 10, 11, item 5).The more detail this subject will be discussed in follow when the inner structures of Unit 111 and Unit 1V would like to be presented.

The Unit 111-1 is (Fig,12) relatively uniform in thickness (about 0.4-0.6s TwT or 0.7-1.2km) and is submitted by series sub parallel reflections which have high-amplitudes oscillations in the upper part and seldom discontinuous low-amplitudes parallel reflections in the lower part of one (Lee, 1992).

The volcanic mound configuration were recognized on the slope of volcanic submarine high or on the continental slope of the Korean Plateau. The Unit 111-1 may have the interval velocity about (2.80 - 3.66)km/s and is distributed in the central and in the southern parts of studied area. The maximum of the thick (about 0.8-1.1s TWT) was

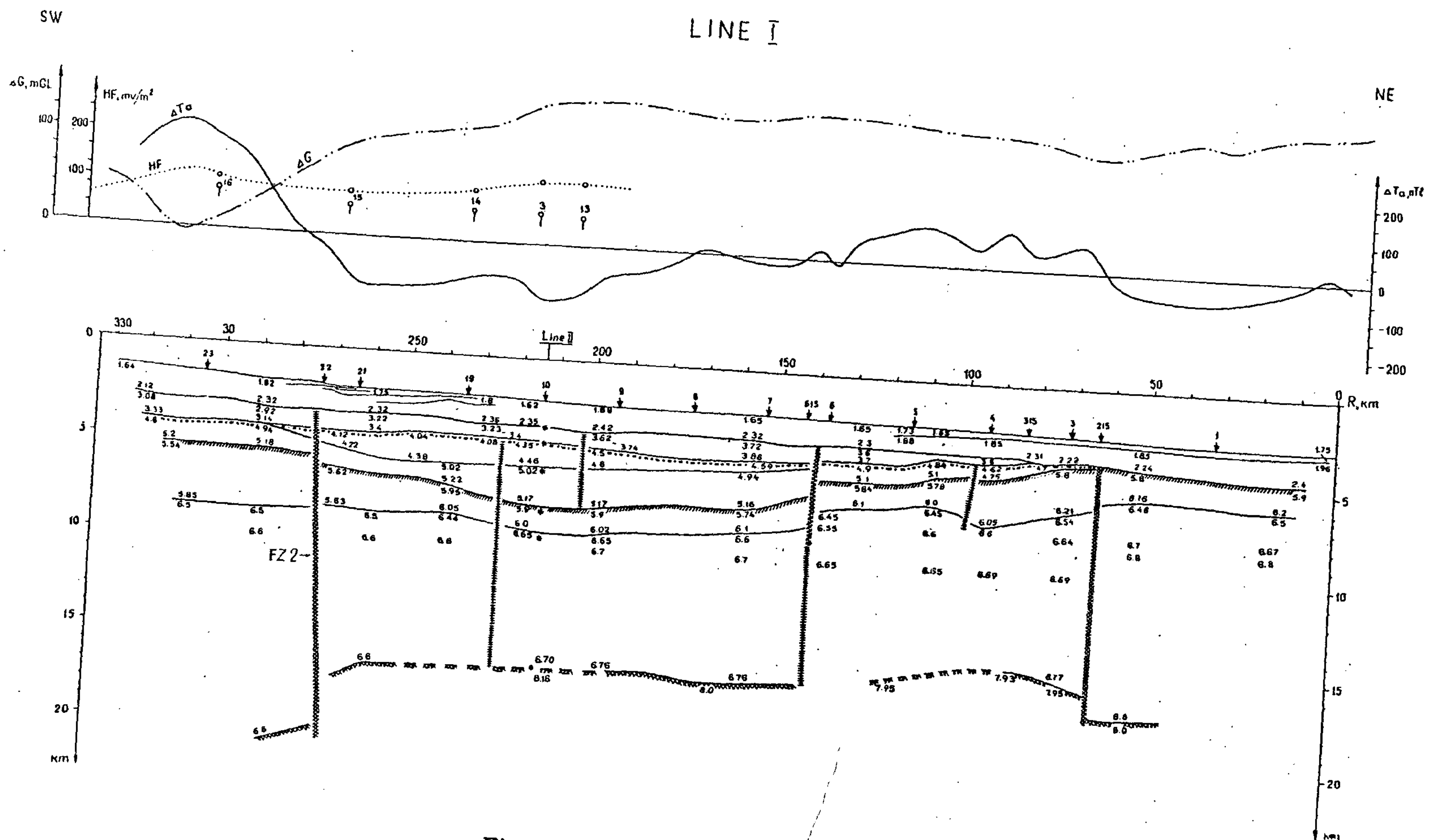


Fig. 10. Seismic section of Line I.

Key: (see Fig.11)

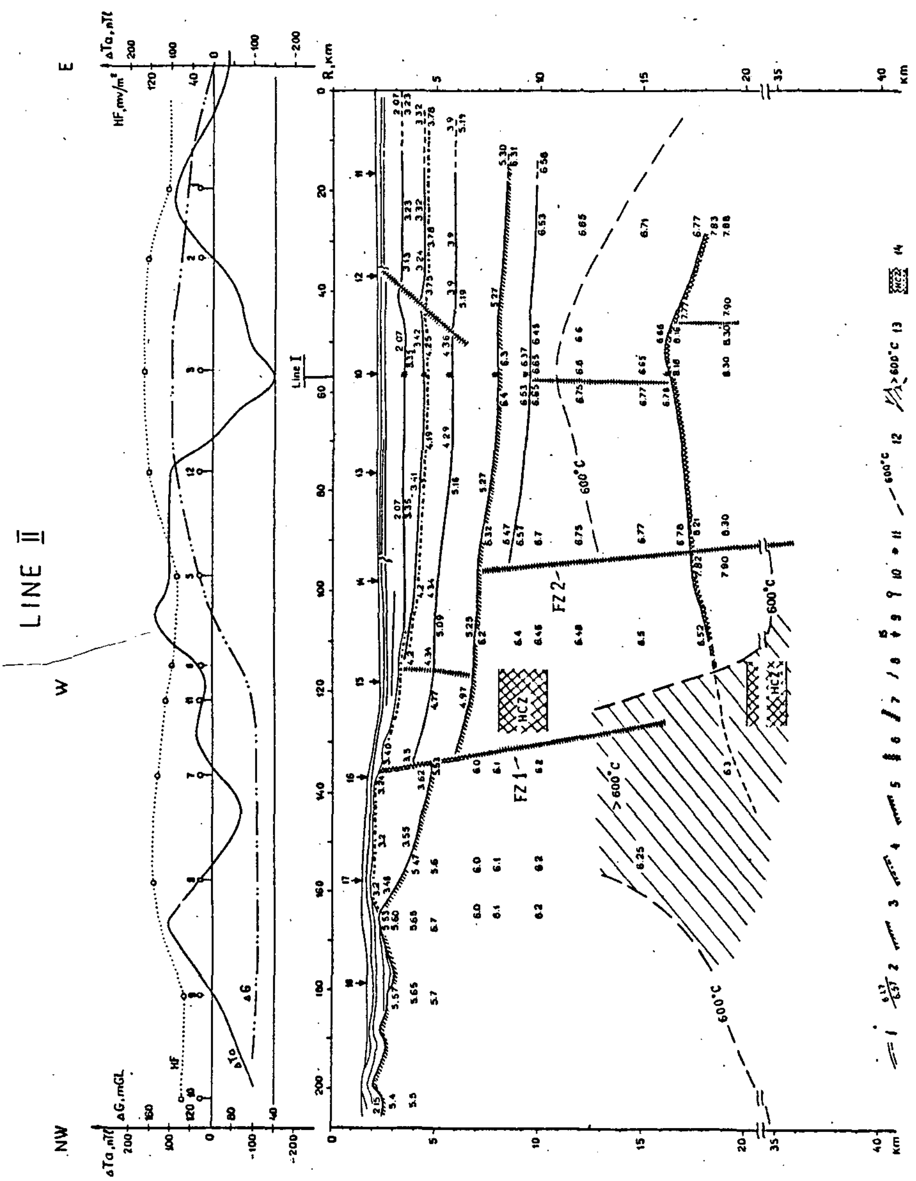


Fig. 11. Seismic section of Line II.

Key: 1-reflectors got from single channel seismic profiling; 2- reflectors with the values of its velocities; 3-Paleozoic basement; 4-acoustic basement may be Neogene; 5-Moho discontinuity; 6-thrust and fault zone; 7-interfaces of vertical change of seismic velocities; 8-zone of qualitative changes of sediment cross section; 9-positions of OBS; 10-position and number of heat flow stations; 11-the interface depth values in the intersection of the profiles, 12-isotherm, 13-the region of higher temperatures, 14-the layers of high conductivity.

Fig. 12. The main cross-section of the crust of the Ulleung Basin along Line 1. OBS data and the multichannel survey was combined, low and gravymetric curve from Fig.II-9 over:

1) OBS-station locations; 2) intersection with reflection air-gun profiles from H.Schluter and .Chun(1974); 3) intersection with the multichannel seismic survey by PEDCO from K.Lee(1992); 4) intersection with air-gun reflection profile from E.Barg(1986); 5) seismic boundaries drawed up: ⓐ-single channel data, ⓑ- multichannel survey, ⓒ- refraction data; 6) velocity distribution as well as relection survey,ⓐ and ⓑ middle layer velocity based on refraction data; 7) layers of Unit 1 and Unit 11; 8) layer Unit 111-1; 9) layer Unit 111-2; 10) layer Unit 111-3; 11)layer Unit 1V-1; 12) layer Unit 1V-2; 13) the faults. The means containing Unit -see in text.

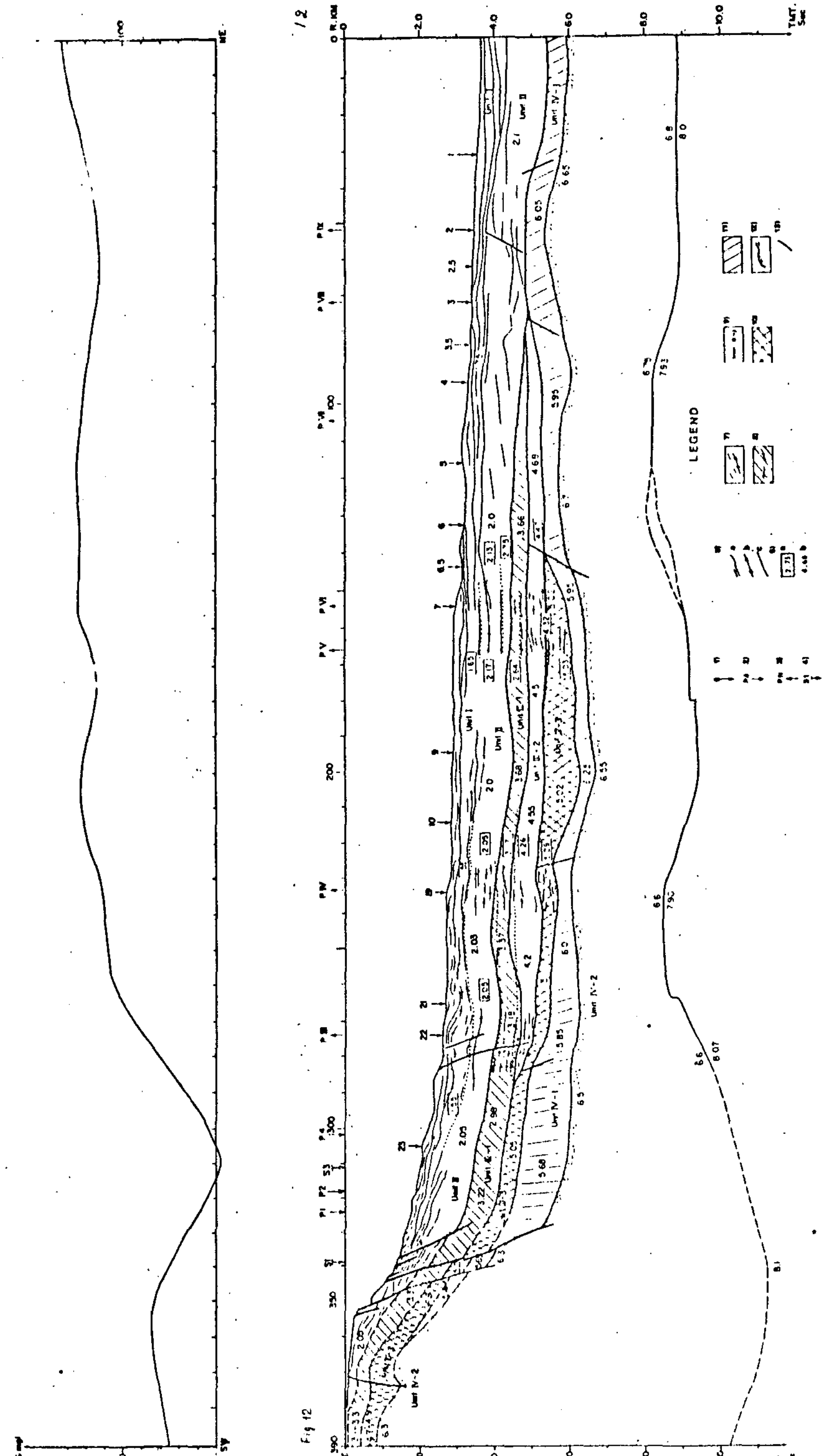


Fig. 12.

pointed up the southern edge of the Ulleung Basin which is situated near on the slope of the southeast offshore of the Korean Peninsula.

The facies of the Unit 111-1 is interpreted as marine shale. In the nearby of the margin depression which was blocked up in view of volcanic seamounts or islands those facies as perhaps are change by massive sandstones or non-bedded volcanoclastic influx from eruptions. As the rightly in those areas were pointed out the increasing of interval velocities. It seems that the ages of this unit may have to be about from end of middle Miocene to later miocene. The Unit 111-1 as means above is underlayered by the strata Unit 111-2.

On the Ulleung Basin this unit is always recognized only by the multichannel seismic survey (PEDCO; Lee, 1992). This strata is characterized by interval velocity from 3.63 to 4.85 km/s. Thicks varies from 1,2 sec TwT in the northwestern part of the Basin to 0,6 sec TwT - in the central Basin and generally onlaps the lower under layering strata. Besides the upper boundary of the Unit 111-2 occurs at or slightly below the volcanic flows extending from the volcanic basements highs (Lee,1992).

However based on the refraction data this Unit 111-2 may have to separate on two indepented layers which is characterized by interval velocity (4.2 -4.68) km/s and (5.02 - 5.28) km/s respectively (Fig.10.11). And thus there is two strata whose need to be discussed separately. The Unit 111-2 is recognized in the central part of the Ulleung Basin beginning from OBS's 3 in the northeast and extending to OBS's 22 in the southwest of area. The maximum of the thicks is fitted in around OBS's 10 and 19 (Fig.12) and consists about 0.8-1.0 sec TwT. It seems that this unit constructs the reliable established ancient depression zone with relatively big sizes (about 200 km along Line 1; Fig.10). According to reflection results the maximum of thicks is situated near the continental slope of the Korean Peninsula on the latitude 36,8 degree. The axis of maximum thicks extends toward ENE direction (Lee, 1992; Fig. 4-2,p70) in strong accordance with the direction of the buried high of the underlayered strata including the basement. The same relative depression is also marked on the southeastern side of this buried high-ridge but it's seems more to point up by the deepest straits. The Unit 111-2 combines of the most part of one arising from reflected method and presents in the term oflayer with "reflection -free configuration, variable-amplitude parallel or programming or low-amplitude parallel reflectors" (Lee, 1992;p.69).

There is the same mainly features of this complex. On the northern and western parts of Basin this unit consists in the view of configuration of reflection the volcanic extrusive or intrusive rocks. On the another side the configuration of low - amplitude reflections construct "chaotic" and "parallel" form which change from northern to southern parts of area may have to bear witness of the stratigraphic wedges that are pointed up here by refraction data (Fig.12). Really it's possible to interpreted as toplap the upper boundary of the Unit 111-3 to the bottom boundary of the Unit 111- 2. In any case the existence of the same features reflected in the structure of the Unit 111-2 are bearing witness about the crucial reliable proofs of the present of the deepest depression zone on the place of the modern Ulleung Basin since before ages of this strata.

In other side this features on the northern part of the Basin is arised on the place of so-called Ulleung Interplate Gap (UIG) situated in area of OBS's 3-6 (Fig. 10). The relations between Units 111-2 and 111-3 and more deepest strata are viewed up as erosion truncation implied the deposition of strata and their subsequent tilting and removal in southern direction along an unconformity surface of the upper boundary of Unit 1V-1 (Fig. 10). Those evidences are the most reliable top-discordant criterion of a sequence boundary and that the

UIG high was more elevation than there is in modern time.

Thus the all reflection and refraction data confirm that the Unit 111-2 characterizes the uppermost of the complex strata which always onlap the upper boundary of Unit 111-3 in area of continental slope of the Korean Peninsula and Korean Plateau (Fig.11) in same manner on southern and western edges of the Ulleung Basin. The all evidences that there is here update may give the reasons to account that this deep ancient basin was developed in the early Miocene-late Paleocene since fulfilled its deposits.

It's not doubt that the initiative composition of the Unit 111-2 was strongly changed caused by volcanic and intrusive processes the tracks of which have wide presented in the structure Unit 111-2 now (Lee, 1992).The variation of velocity in this strata are evidenced on those conclusions.

The Unit 111-2 is underlayered the stratigraphic sequence named Unit 111-3 and which have been established as independent and itself determination by only refraction data. Really according to reflected seismic method Unit 111-2 had been established as the stratum which have to lie ahead for the acoustic basement. On the whole scale of the depth this seismostratigraphic sequence haven't the stable seat and being characterized by interval velocity from 2.4 km/s on the continental slope area to 4.7 km/s in deepest parts of Basin.

The lowermost-bottom of strata is pointed out as the transition zone or erosion surface. In this case the acoustic basement comprises reflection-free configuration, whereas the basement have discontinuous, high-amplitude, parallel reflectors and smooth surface (Lee, 1992). In any times the acoustic basement can also be not clear and may be characterized by mound configuration that is displayed as the various latterally reflected amplitude, frequency and continuity.

However the acoustic basement was origionally defined as not flattening gentle surface but as well as the reflectors which may have to image in the term of hyperbolic diffraction patterns originating from irregular topography of its surface.

The same and similar patterns have been established only in the northern part of the Ulleung (so-called above north sub basin) Basin where the acoustic basement is became true. In central Japan depression and it is essentially arised on the Yamato Basin the acoustic basement are coincided as means above with the complicity stratigraphic unit that is to be indicative the interlayred sediments and volcanic sills (Tokuyama et. al., 1987). Driling results of ODP Leg127 and Leg 128 have confirmed that the acoustic basement isn't constituted with that of the geological and it combines sediments and volcanic rocks and basalt sills. It's more that volcanic and basalt rocks have evidently the most youngest ages than the sediments containing those volcanic rocks. If it's based only on the likeness of seismic images due to the reflection data with those of the Yamato Basin the acoustic parametries of the Unit 111-3 indicate that this unit may also be named as acoustic basement in its usual sense. It apparently also contains the volcanic flows and sills. However the results of refraction data bears witness to the same principal part of the composition of this strata is more came true as methamorphic sediments layer so as liken as same on the lands coast of the Korean Peninsula. The proofs of those consideration is as follows:

1. As rule the acoustic basement is characterized by the irregular topographic surface under which the reflectors are not recorded. The acoustic basement as it have been defined originally isn't to be transitional zone or layer.

2. The all acoustic features of the Unit 111-3 is just enough similar to those of the Unit 111-1 and Unit 111-2. They may combine to at all as uniform seismic units but separated only by velocity

distributions and by changing probably composition of sediments.

3. The Unit 111-3 as the lowest part of the Unit 111 and "transparent" part of Unit 11 are continued on the slope and the top of the Korean Plateau where it is characterized as normal geological strata defined on basis of the dredged results which have been producted in adjacent areas (The main ...,1978).

4. The many evidences based on seismic data confirm that the Unit 111-2 onlaps with trancations on the upper boundary of the Unit 111-3 what are suggests to combine the stratigraphic erosion surface with this boundary.

5. The ages of the Unit 111-3 may be estimated as early Paleogen -later Cretaceous of ages until the volcanic activities of Ulleung-do and Dok-do area based on the volcanic rocks and basalt sills in inner parts of this Unit have been conducted to become true. It seems the most youngest as well as it have been established in the Yamato Basin.Thus in this view the Unit 111 - 3 may have to be included in composition of sediment shell of the Ulleung Basin as well as the representative metasediment strata that's just like those which are discripted on the Gyeongsang Basin (the Gyeongsang strata ?) on the southeastern of the Korean Peninsula and on the southwestern Japan (Choi et. al.,1981;Inoue,1982).

Before completion of this paragraph it is need to point out that from all seismic data there are following the anomaluos features of both cover and basement structures. It is possible to regard that the local anomaluos pattern which have been established over the seismic cross-section may have to be combine in the term of complexity lineative structures expending through the Ulleung Basin area. These lineative structures are correlated on base of published works (Lee, 1992; Fig.-s 1-4,3-3,3-5,3-6,3-7, 3-8,3-13,3-15,3-16,3-17) and refracted data (Fig.10,11) as follows.

1) the first zone (buried ridge 1) :

On the Line-PEDKO 4 there are situated on

Shot-Point(ship)-7700:7800;

Line-PEDKO 3 .... on ship - 6300:6500;

Line 11 - IMGG there are situated on the area of OBSs

14,FZ 2;

Line-PEDKO 6 .... on ship -- 9200:6500.

2) the second zone (buried ridge 2):

On the.. Line-PEDKO 2 there are situated on ship- 3200:3400;

Line-PEDKO 3 .... on ship- 3400:4000;

On the Line 1 -IMGG there are situated on the area OBSs19;

Line 130-IMGG............ on the area point 10*hour;

Line-PEDKO 4 .... on ship- 6500:6900;

Line 11-IMGG .... on the area OBSs 13:14;

Line -PEDKO 6 .... on ship - 8000:8300.

3) the third zone (buried ridge 3):On the Line -PEDKO 2 there are situated on ship- 1300:1500;

On the Line 11 - IMGG .... on the area OBSs 12:10;

Line -PEDKO 4 .... on ship- 4800:5100;

Line-PEDKO 5 .... on ship -3900:4200;

Line 1- IMGG .... on the area OBSs 7:8;

Line - PEDKO 6 .... on ship - 17200:17500.

These buried ridges are always displayed by practically of over all reflected and refracted interfaces either strongly or weekly degrees but at least of several of their closely fit out by the sea bottom relief. Besides in many cases these features are accompanied by the faults and the fracture zones.

4-3-4. UNIT-1V

The Unit- 111 as the whole stratigraphic unit of sediment cover overlayer the Unit-1V which is looked in the term of the basement of the Ulleung Basin structure. This Unit-1V is evidently arised and characterized by the refraction OBS's data. The physical and acoustic properties of this bear witness that nearby on the slope of the southeast offshore of the Korean Peninsula (see above, Fig.12) are displayed the many liken features to those of the gneiss complex and included methamorphic sediment. This unit is to be very strongly changed its composition that is pointed out by the progressively varying of the velocity from 5.68 km/s near on the shelf to 6.05 km/s on the northern part of the Ulleung structure due to just closely those by the approaching to the volcanic centers and overlaying the domefull uplift of mantle plume here (Fig.10,11). The down depths of the cross-section the Unit-1V under bedded unconformably by the crystalline basement which is characterized in the term of the seismic image as strata with interval velocity 6.3 km/s on the shelf and land area and progressively increasing toward northern direction according to the behavior of the upper layered strata. It's seems the really that the ages of two last unit may have to define as the middle-early Cretaceous to upper and Pre-Cretaceous - to lowest. It's not doubt that told conclusions are prior and it need the detail land-marine investigations by refraction waves after which those speculations will be became true.

On base of the map (Fig.9) showing the area distribution of seismic facie configuration patterns for Unit 1-1 and for the acoustic basement it's seems possible to assume that:

1) the acoustic basement have to be coincided to that of the

geological basement on the uplifted edges of the Oolong Basin and are dated by Pre-Cretaceous age;

2) the acoustic basement have to be closed to roof of more young sequences as Unit 111-2 and 111-3 on the central axis zone of the Ulleung Basin. It's need to emphasize that Unit 111-2 have the limited expansion and have been met on central area of the Ulleung Basin only (Fig.) and had not to be found on the offshore and inland of the Korean Peninsula;

3) there are to be established based upon the compression between distribution both patterns of Unit 1-1 and the acoustic basement (Unit 111-2) that the boundary of the deepest part of the Ulleung Basin are to stable on those actual outlines since at least from the Early Miocene age.

4-3-5. FINAL REMARKS

The sediment cover have been study by reflection seismic methods and refraction seismic OBS survey. It assume to look upon this results as crucial proofs on the discussion around both the origin and evolution of the Ulleung Basin and the East Sea as whole. The principal minds of those are formulated as follows.

1. The reflection and refraction data concord (Fig. 12)as well as possible in the term of Two Way Time (TwT). From those data there is followed that sediment cover may have to characterize as the two -floor strata the uppermost of which (Unit 1 and Unit 11) is attributed a sufficiently low interval velocity and uniformed structure and its the lowermost contains the relative high and high velocity layers that strongly varies in view of the inner structures. On base of this reflection data there are showed that from northward to southward the youngest sediments progradetively lie down on the progressively

younging acoustic basement. In the last it's established 4 comlecacy units of the their inner subdivisions which separated by the structure ,interval velocities, compositions and ages.

2. Unit-1 and Unit-11 are uniform over the whole basin and over the environment areas. The Unit-1 have been indicated unconformities and disconformities in its the uppermost that are bear witness of relatively active evolution in the modern time.

3. All seismic boundaries are to be sharp and over the main part is fixed as naitus sequences.

4. In the central part of basin near on the southern edge of the Ulleung-do are established the ancient depression zone which in historical time fulfilled by sediments. Extending of this basic depression coincide with those principal extending of the structures of Korean Peninsula: NEN- SWS as the Yangsang fault-fold zone but having a bit clockwise rotation in respect to trend of ones. The ages of these movements which provided the same direction of this depression zone may have defined as late Cretaceous - early Paleogen. It is strongly suggested with that establishing over oriental offshore of the Korean Peninsula (see in follow, Fig.25).

5. On the north-western-north area have been established the sediment basin-through with wide as well as 30-40 km and depths about 1.25 sec TwT which is may be the south-western-south edge of the Ulleung Through. There are many another temptations to look out this structure as the shifting which continue the Mucko Basin of the Korean Peninsula coast. But there isn't the crucial evidence to that from actual data.

6. The several anomalous zones extending as the narrow belts relatively parallel to the axes of the ancient depression zone referred above on base of reflection and refraction data are represented in the term of the buried ridges. The extension of those ridges are in

harmony with principal direction of the Korean Peninsula structures as well as NEN-SWS but also having a bit clockwise rotation .

7. The geological basement of the Ulleung Basin in accord to refraction data are evidently defined as Pre-Cretaceous of ages.

CHAPTER 5

DEEP CRUSTAL STRUCTURE

CHAPTER 5. DEEP CRUSTAL STRUCTURE

To understand the deep crustal structure of the Ulleung Basin by OBS data , it is necessary to look out the adjacent and surrounded crustal structures. However, the available experimental and comparable kinds of data have not been provided around the Korean Peninsula except the gravimetric field survey.

It seems important that reviewing of the available evidences on the the structure from gravimetric survey should be analyzed herein before main discussion goes on.

5-1. Gravimetric Data Fields

The Bouguer anomaly of offshore of South Korea and the Ulleung Basin are shown in Fig. 13. The data used are both from the published material (Geology., 1987) and from the surface ship measurements by KORDI. The South Korea are characterized by Bouguer anomaly patttems which range from values -30 mGal to +60 mGal and main trends NNE can be shown due to anomaly distributions. The anomaly field progressively increases toward to offshore and to the Ulleung Basin reaching the maximum values higher than +60 mGal is a distinctive feature along the coastline and shelf area. It is probably caused by the diminishing depth of the crust developing here wide Tsushima-Goto Fracture Zone. However, considering the middle level of the Bouguer anomaly field onland of Korea, nearby vicinity of the East Sea, and continental slope areas, many similar features are established. So the total values of this fields

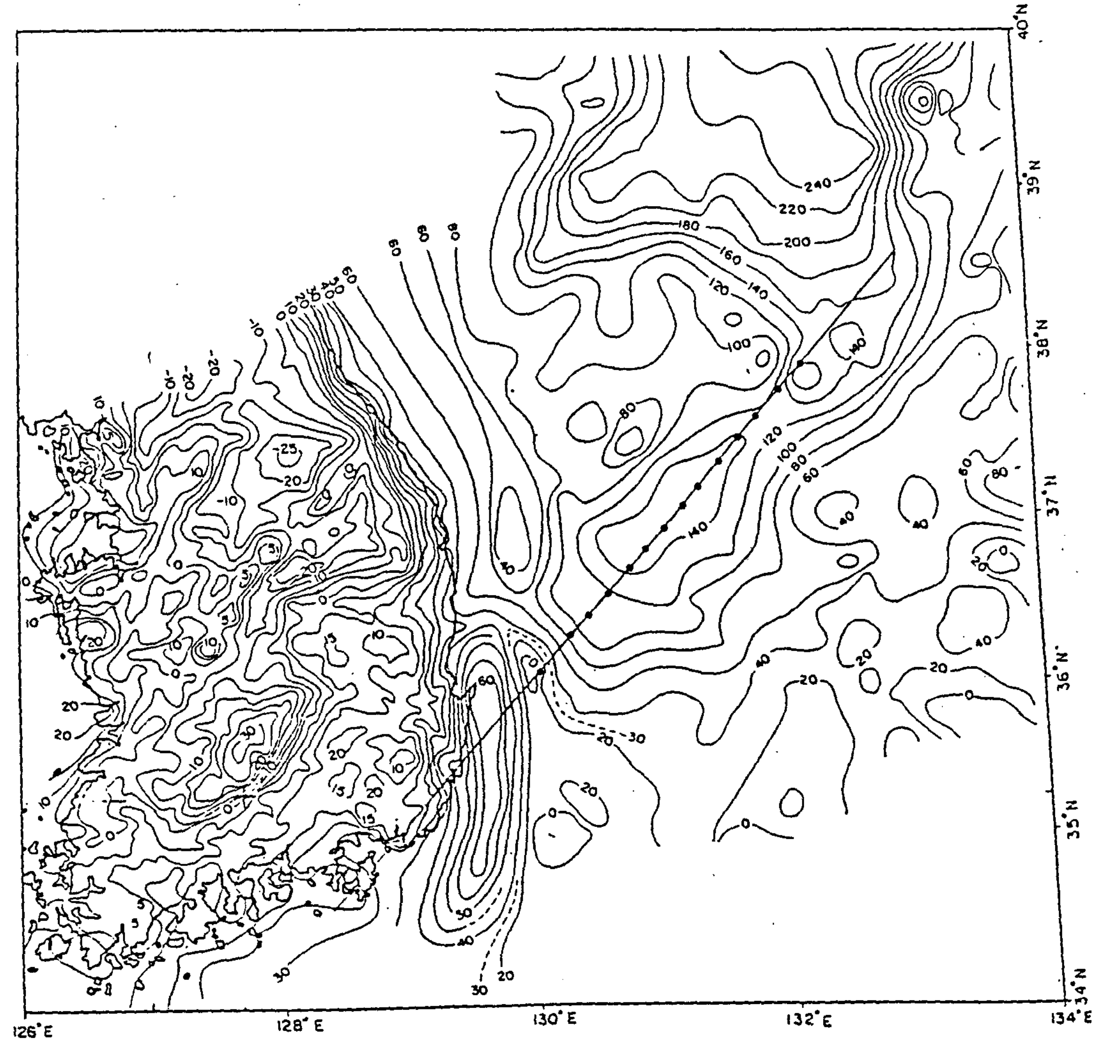


Fig. 13. The Bouger anomaly maps of the Ulleung and Korea Peninsula Areas. Compiling by using (Geology.,1987) and KORDI. Contour lines in mGal. The line with dark circle are Line 1 - OBS data.

is not more or is not less than "+10 mGal" or "+ 20 mGal" levels exept the anomaly patterns.those evidences are significant beared witness due to the similar crustal and its physical properties. To far toward to NNE from the Korean Peninsula and WNW from Kyushu Island the Bouguer anomaly rapidly increases to the central part of the Ulleung-do Island to the values +140 mGal and more. The mean Bouguer anomaly field is the somewhat higher on the whole northern part of the East Sea (Sea of Japan). However, compared to the Ulleung Basin the principal features are slightly recognized. There are NEN-direction of Bouguer anomaly patterns established. Those anomaly zone wide as 35-40 km and ranges longer than 200 km. There is a relative decrease of the field of about 15-20 mGal in UGI-area.

In another side, there are yet one of the significant features of the Bouger anomaly field of Ulleung Basin Area. The assymetrical patterns of the field are recognized. In fact, the WNW-side nearby Korea Peninsula offshore the narrow strip-laken transition zone from Peninsula to the Ulleung Basin are arised (the amplitudes of anomaly closely extend to +60mGal) until the environmental domain of the Oki Bank structure and shelf of Kyushu island (the amplitudes anomaly closely trend to +20 mGal nearby to island and +40 mGal on NW trend). The transition zone between those patterns of the southern edge with very high gradient are displayed. Before conclusion of this item it is remarkable that the conjections between offshore Pohang of Korea,the northern extension of the Tsushima-Korea straits and the southern part of Ulleung Basin induce the triangle zone with the contrast gravymetric patterns due to tectonic features (stress ?) and the deepest sediment basin of the southern corner of the Ulleung Basin.

Best known that the dynamic state of the earth's crust and the upper mantle are usually estimated from the analyses of the isostatic anomalies. On the East Sea area as whole and on the Ulleung Basin as partly the isostatic anomalies have been calculated by P. Stroev (1973)

According to those data, the deep areas of the East Sea are characterized by the smooth positive isostatic anomalies. The highest level of those are remarked on the area of the Tsushima-Korean straits.

The strong complexity of the patterns of the isostatic anomaly fields have been pointed upon the shelf and the continental slope of the Korean Peninsula and same of both the Honshu and Kyushu Islands. There are the sharp lineations of same isostatic anomalies trending along the coast lines. In any case, those features are interrupted by the reverse systems of anomalies.

The negative isostatic anomalies are widely extended over the submarine rises and the Korean Borderland Areas where the continental types of the crust were established.

It is likely that the same areas and another which are also remarked as well as the regions attributing the negative isostatic anomalies but belonging by the least amount of the squares might be defined as the remained blocks of the continental crust. Usually those blocks are regarded as the remainders of the continental area extending here (Fig. 13) before the origin of the East Sea (the Sea of Japan). However there are not the crucial proofs which would be opposited on the opinion that these blocks have been constructed by the modern tectonic processes (The Main., 1978).

But in any way, the small positive isostatic anomalies over the East Sea as a whole give an evidence that the uncompensated isostatic alignment essentially into region of underwater rises where the reconstruction of the Earth's crust and the upper mantle structure are continuing. Furtheremore it seems that the principal role in the tectonic movements here continue to play the layers situated inner crust and upper mantle with the low density effect. Undepedently from these or another explanations of those reasons (The Main, 1978) the depressions have tendension toward descending and the framework of the East Sea are fitted to uplift (to float on the surface)

5-2. Gravimetric Modelling of the crust around the southern part of the East Sea

5-2-1. Input data

The modeling is performed with the two crossed profiles, where the deep seismic sounding data were made. As an input gravity field, Bouguer anomalies are digitized from the maps with 10-20 mgal contours.

The calculation of density structure was made with PC-AT/286 2-D gravity modeling program; ihomogenities of topography and deep structure was approximated by infinite horizontal prisms with the base of trapezoid form with vertical lateral sides.

5-2-2. Compensation of density sections.

Region under study compose the offshore of the Korean Peninsula and the adjacent Ulleung Basin. The bottom topography ranges from 0 to 2.5 km that allow to speak about continental and at least the ocean types of crust. As is generally known this two section types differ in deep density structure not only over earth crust but in all tectosphere depth. In contrast to ocean section the continental one is characterized by the thicker lithosphere and weakly pronounced or absent of asthenosphere layer. To understand these inhomogeneities the sections must be referred to the standard Earth model. But because of the insufficient data of asthenosphere and lower part of the crust, it doesn't do that. Reference sections must be made to the most stable part of region under study; in our case that is the eastern part Korean Peninsula or its shelf zone. The seismic data provide the information of only upper part of Korean Peninsula earth crust (western part of Line I, Fig. 10), the Moho and Conrad discontinuities are traced uncertainly here.

There is another problem for the initial stage of gravity modeling the problem of mutual section coordination . Calculated models are crossed in the central part of the East Sea and show some disagreement with the seismic structure (Fig. 10, 11) which may be caused by the media anisotropy. The density columns of two sections in the point of intersection calculated by the seismic velocity values with the empirical relation Nafe & Drake are presented in the Fig. 14 (columns 1 and 2). As is shown, the columns differ not only on the densities, but also on the thicknesses of layers. The calculated gravity field of these columns cause the residual value of more than 30 mgal. To remove this discrepancy, the crust foot of 1st section was raised through 1.2 km up to the level of 2nd section, and the crust density of 2nd section was decreased by 0.005 g/sm^3 up to a correspondence with 1st section. Note this operation of removal the discrepancy doesn't clear the problem, and possibly produces an additional error in our calculations, but one must know the matter of seismic data discrepancy.

Further calculation of gravity fields were made for the a prior density models of 1st and 2nd sections matched with both the experimental and calculation values in the point of intersections. A prior density models were constructed based on seismic sections by the empirical relation Nafe & Drake. On the part of continental shelf the positions of the Moho and Conrad discontinuities was determined according to the model of K. D. Miln (Geology of Korea, 1988, p.250).

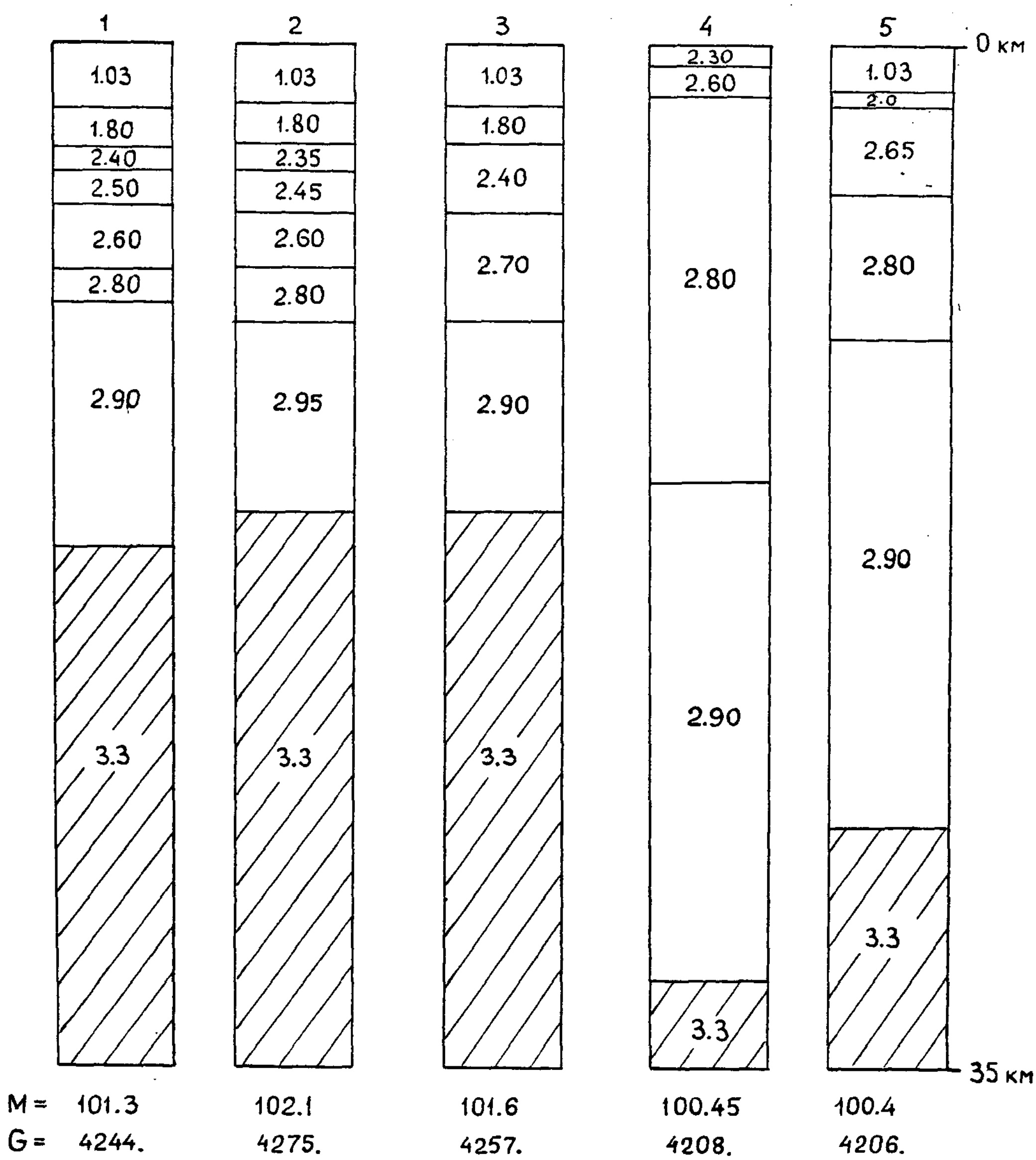


Fig. 14. The equalizing of density columns for the mutual coordination of sections.

Key: 1,2-the initial density columns of 1st and 2nd sections, respectively, in the point of their intersection (Tsushima basin); 3-accepted as a reference the average density column of Tsushima basin; 4-accepted for the calculation the density distribution of Korea Peninsula shore; 5-according to gravity field the isostasy non-compensated column of north-western part of region under study (section II). For the each density column the values of specific mass ("M", g/cm**3)*km) and gravity field ("G", mgal) calculated by the formula for the infinite plain-parallel layer are listed.

The computation showed the match levels of 1st and 2nd sections gravity curves differ by about 15 mgal. Caused of this discrepancy is the shape and structures under study is different significantly from their 2-D approximations used for computation. In order to remove this discrepancy, we attempted to estimate the effect of neglecting mass and made a corrections to the calculated gravity field values as a regional background. Because of all 3-D inhomogeneities have been included in the Bouguer anomalies the maximum error is introduced by the deep mass and variations of Moho in particularly.

The crust thickness of our region vary from 30-32 km to 16 km. As it show the seismic data there is a rather clear differentiation between the ocean crust proper (thickness of 16 km) and the subcontinental one with the thickness up to 25 km. Fig.15 (dashed line, upper part of Fig.) show the effect of subcontinental crust block at the distances of 0-200 km from it. Considering the Ulleung basin and its north-eastern extension are limited by same blocks on both sides, the effects of this block must be redouble all over the 1st section, and the maximum correction value is of about -50 mgal on the north-eastern part of 1st profile. In addition the calculation of continental crust effect, which was a fraction of last and was distinct on the 2nd Line was also made.

The value of total calculated correction over the 1st Line vary from 0 to -50 mgal, over the 2nd Line from -7 to -15 mgal and in limits of Ulleung basin reach -25 mgal on the 1st profile and -10 mgal on the 2nd profile. Furthermore the effect of this mass was accounted as a regional background approximated by the third degree polynomial through the density section modeling. For determination of regional background coefficients the correction values were calculated at the ends of profiles and at the most characteristic points were used.

After the completion of these operations, both density sections

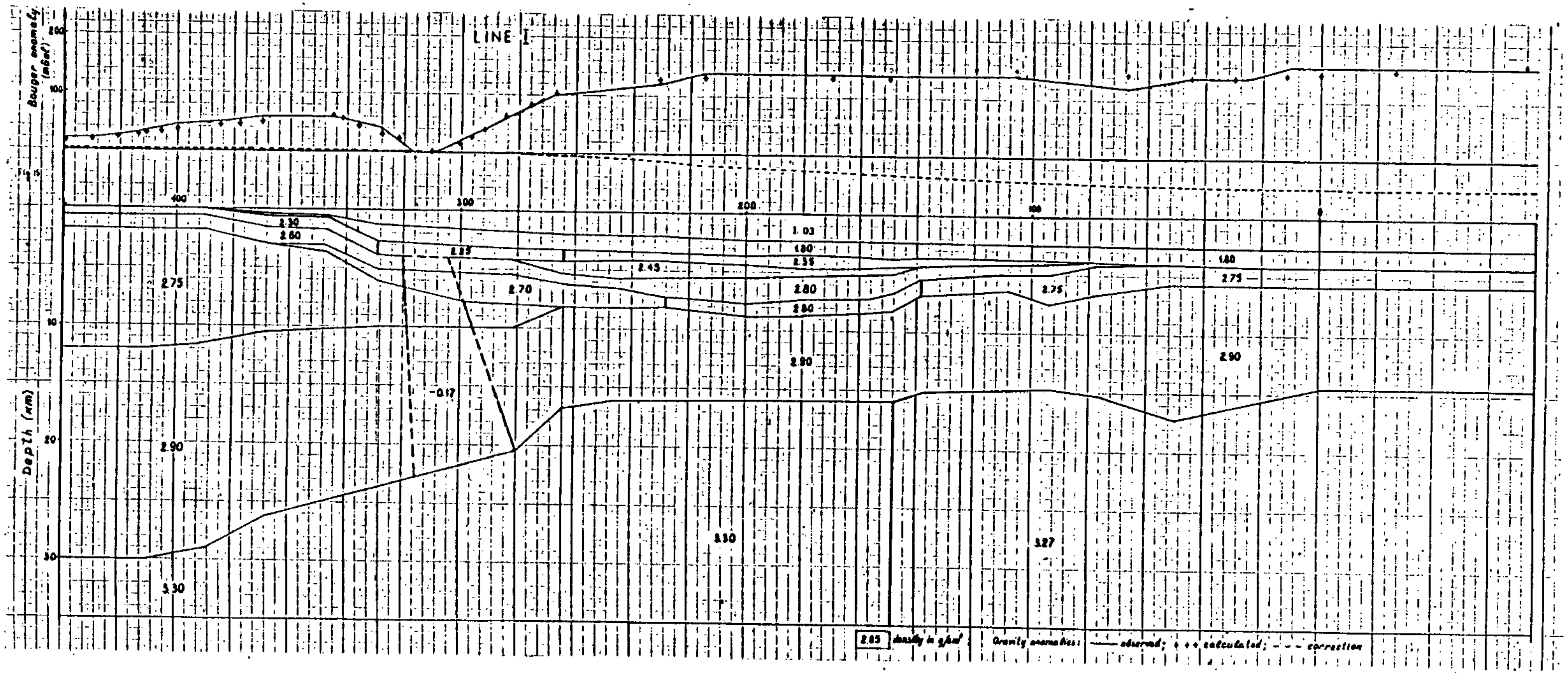


Fig. 15. The density model of Line I.

were found to be correlated between themselves on the distribution of density at the point of intersection and on the reference level of gravity field. It must be noted that the performed estimate of deep inhomogeneity effect is likely most possible.

5-2-3. Exposure of density inhomogeneities

The next modeling step were an exposure of regional parts, where the observed and calculated gravity fields were not coincide, and the attempts to its explanation by the use of additional information (such as heat flow data, tectonic features, etc.) or by the shape of residual anomalies.

It was distinguished 3 such parts :

1) the north-eastern extension of Ulleung basin (north part of Line 1);

2) the north-western extension of Ulleung basin with a smooth topography and a minor thickness of sedimentary layer (Line 11,Fig.11);

3) the narrow zone of very strong negative anomaly on the part of continental slope (Line 1,Fig.10);

In bottom topography the north-eastern extension of Ulleung basin are represented as a stretch, weakly deep and relatively narrow zone. In comparison with the Ulleung basin this zone is characterized by some greater depth, less thick sediments and increased values of heat flow. The observed trend of the Bouguer anomaly patterns increase in the north direction. In the residual gravity curve this zone is characterized by the negative anomaly of about -50 mgal, which decrease up to -25 mgal after the correction. Taking into account the upper part of section is investigated quite well the obtained anomaly may be explained by the structure of crust lower part or lithosphere. For the compensation of this anomaly either the Moho discontinuity must be lowered by about 1.2-2.5 km or the density of lithosphere must be decreased by about 0.02-0.04 g/cm^3 if this density decrease is assumed up to 50 km. Taking account some increase of heat flow and more or less reliable determination of crust thickness by seismic data the second assumption is more justified and is realized in our models (Fig. 15,16).

The narrow gravity minimum at the boundary of continental crust is caused by the lower rock density of all over the crust thickness if one may judge by the anomaly shape and intensity. The shape and value of -0.17 g/cm^3 of this low density body was selected by residual anomaly, separated from the section. The body has the isometric shape with some slope to the sea (Fig. 3b). This low density effect is assumed to be related with the deep fault situated there.

The subbottom region with the smallest uplift of bottom of about 0.5 km and thin sediment layer is situated toward the north-western from the Ulleung basin. This zone is characterized by the very low level of gravity field as 50 to 60 mgal, which is not subject to be attributed for the deep sea bottom. It points that this region are not isostatically compensated.

Apparently the non-great size of this block allows it in the dipped state by reason of the cost of lithosphere rigidity. The seismic data point the increase of crust thickness and possible decrease of its density here. Model represented on Fig. 4 is designed according with the assumption that consolidate crust density is reduced by 0.05 g/sm^3. As the calculation showed the decrease of consolidate crust density by 0.05 g/cm^3, the crust thickness matched with the observed field is about 24 km.

In any way, if the all computation models of upper part of lithosphere here should be related to the results of the seismological and Heat Flow exploration (Abe and Kanamori, 1970; Yoshii, 1973;

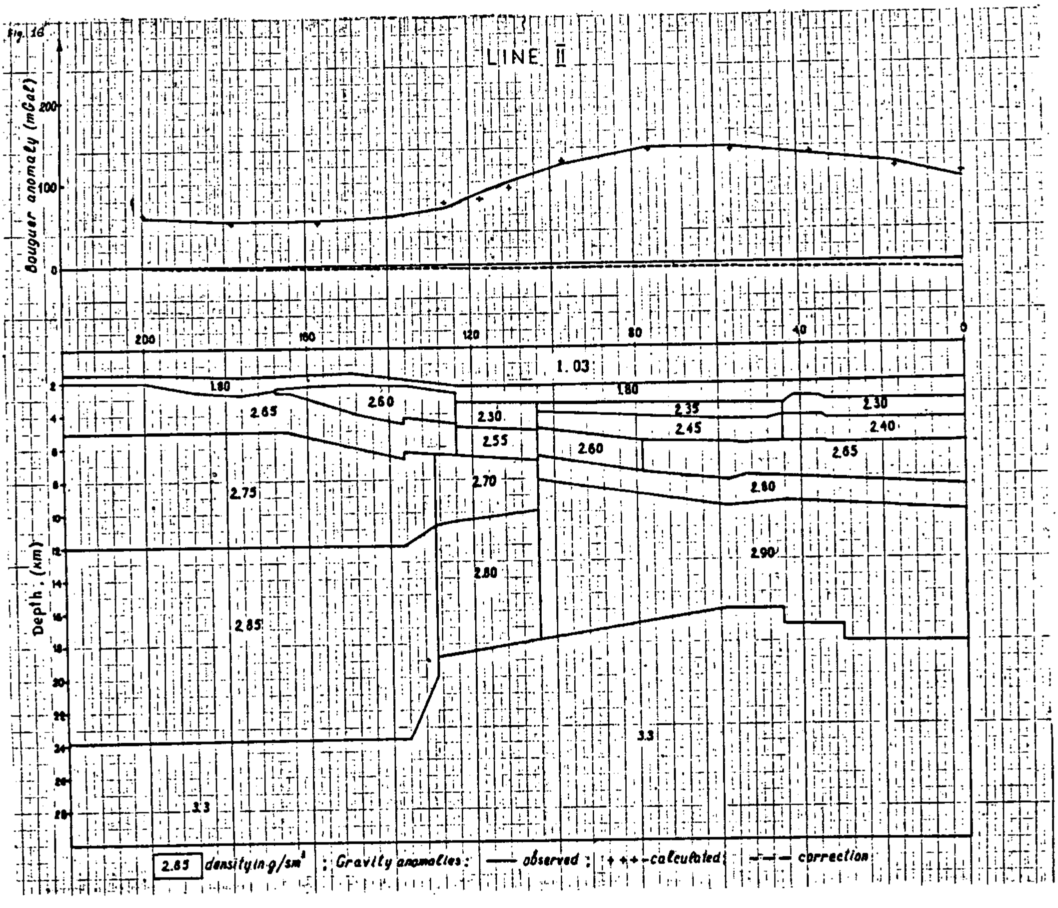


Fig. 16. The density model of Line II. (Key see Fig.15)

Kobayashi., 1985), the low density layer over the depth range 30 to 60 km must be accounted. Thus the density distribution in the upper mantle under the Ulleung Basin received by gravimetric modelling are to be corrected over those data, and thus, compared with another geophysical methods in partly magnithovariation results.

5-3. GEOMAGNETIC FIELDS

5-3-1. Field of the Geomagnetic Anomalies of the Ulleung Basin.

Detailed and systematic study of the field of the geomagnetic anomalies of the East Sea (Sea of Japan) was carried out during the many years since from 60th. The analysis of experimental data was made by the quality consideration of the magnetic field isolines maps or anomalous field graphs along the profiles.

There are two approachs as a base of this analysis:

1) the formal analysis of anomalous field features and the search of correlative relationships due to the geological structure of continental marginal, topography and substance composition of acoustic basement;

2) the search of regional stripped character of anomalous geomagnetic field and comparison these pattern with the theoretical anomalies calculated on the base of spreading models. The spreading velocity is obtained by the comparison of the calculated data with the magnetostratigraphic scale (Vine-Matthews method).

Detailed analysis of all available geomagnetic field data allow to determine the basic knowledge of its feature, which is caused by morphological features of the sea bottom and geological structures of the Earth's crust.

Thus it may regard to be establised (Koboyashi, 1978) :

1) the peak-to-trough of field intensity can reach 100-450 nT. By the wavelength the anomalies subdivide into the high frequency group of anomalies with the wavelength of about 20-40 km and low-frequency regional one with the wavelength from 400 to 2,000 km;

2) the magnetic lineations due to spreading nature of marginal seas were partially established in the central deep depression of the East sea. The trend of the axises of these anomalies lie in the direction of N60 E and appears to be parallel to the general trend of southwestern Honshu Island;

3) in the western part of this deep depression of the East sea and Yamato Basin, these anomaly lineations are indistinctly displayed, but where it is possible one may be separated their trend lie also in the same direction N60 E. In the north-eastern part of this deep depression , near the Hokkaido Island, the direction of trend changes to the NE-SW and NNE-SSW;

4) on the Ulleung Basin, it is impossible to establish the lineations because of field pattern irregularity. In the same time, the regions of its negative values display some regularity, which cannot be coincided the identity of spreading magnetic lineations, however.

As the whole, in the East Sea Basin the identification of magnetic lineations on that of magnetostratigraphic scale is very difficult. It is defined by both a small amplitude of the anomalies and the transform faults disturb often their linearity, and also caused from the effect of hydrothermal modifications.

As is known, the main features of anomalous geomagnetic field are attributed to the deep faults and fracture zones. This connection is displayed especially clear in the regions of continental and island slopes. The more calm field of depressions suffers the effect of fault systems of different orders and is locally disturbed in the regions of subbottom mountains and hills.

Following M. I. Krasniy (1969) and Yu. V. Shevaldin (1978), in the anomalous geomagnetic field of the East Sea it may be exceptional a number of regional anomalies, two of them coincide spatially with the region under KORDI-IMGG study in outlines of the Ulleung Basin.

Thus the North-Korean anomaly characterizes a major area in central and northern parts of region under study. This anomaly may be subdivided into North-Korean and East-Korean anomalous zones.

The North-Korean anomalous zone is related in its most part to the Wonsan Bay and is corresponded to the Vonsan Trough and Wonsan Plateau morphostructures (Fig.1, 5). It is discribed by the normal and lower intensity of magnetic field. The submeridional, sublatitudinal and north-western directions prevail in the field structure. The upper edges of magnetic sources are generally located in the upper part of the crust section.

The East-Korean anomalous zone is situated in the south-western part of sea and related to the East-Korean shelf. The north-eastern directions according to that of the Korean Peninsula is characterized for the western part of anomaly.

Off eastwards, the directions of anomalies change to the submeridional and sublatitudinal ones. The submeridional trend of anomalies are represented in the main by a negative field.

To the just of the south of region under study, the Tsushima anomaly represented by the system of submeridional zones with, in the main, the negative field stands out. The three areas of higher field level(more than 200 nT), which decay towards the latitude 37 N, stand out here. At the same time the axis of these anomalies may be traced trough all western part of East Sea by the many different correlational attributes.

Near the Korean-Tsushima straits area, this anomaly is under active study to establish its correlation with the surface of "magnetic basement" and the granite and volcanic intrusive zones (Park et. al., 1991). It has been shown the high level of local anomalies near to the south-eastern seaboard of the Korean Peninsula appear to cause by the granite intrusive bodies or volcanic rocks. Magnetic basement formed here by the complex of tuffs, basalts and sediments and defined by (Park et.al., 1992) as a top of second layer in the Yamato Basin and Central deep depression of the East Sea (Sea of Japan). It appear to be occurred at the depth of 2.6 km in the south ("200 m" isobath) and dips up to 7.0 km to the north-east near the "2000 m" isobath. This results is in good agreement with the depth of refractor interface with velocity of 5.55-5.85 km/s obtained by refraction wave data of profile 1, as mentioned in part IV (Fig. 15).

However, this seismic boundary is more strongly corresponded to the top of Pre-Cretaceous geological basement of the Korean Peninsula and is not to be as the top of second ocean layer. The data of profiles III and IV consistent with the section of profile 1 corroborate this consideration rather positively.

The Oki-Bank anomalous zone, which is represented by the substantial of area attributing the low gradient, negative and positive anomalies, adjoint to the Tsushima anomaly. Directions of anomalies are north-eastern.

Based on the anomalous geomagnetic field map of Yu.V Shevaldin (Shevaldin,1978), the skeleton-diagram scheme of anomalous geomagnetic field of the Ulleung Basin (Fig. 17) and contiguous areas (Fig. 1, 2 ,3) were constructed.

Shade anomalies with the negative level of field reach the intensivity values of(-100 -250) nT whereas the positive anomalies (not shade areas on the scheme) reach more than 250 nT.

This scheme-diagram show the directions of negative anomalies

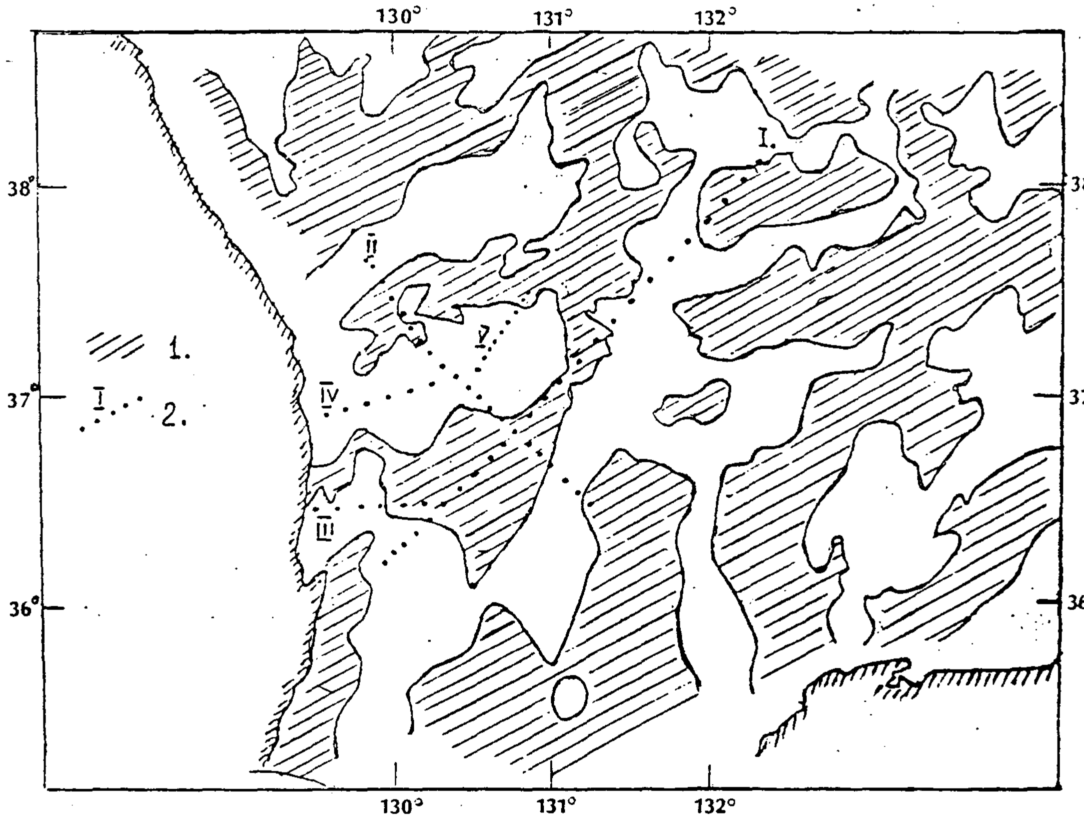


Fig. 17. The skeleton-diagram map of anomalous magnetic field over the Ulleung basin.

Key: 1-negative anomalies; 2-seismic refraction profiles.

are north-eastern in the west and east-north-eastern in the east; the directions of anomalies become submeridional in the south and to the north, in the central part of region become submeridional and sublatitudinal. In spite of an apparent linearity of negative anomalous zones they correspond poorly to the typical ocean magnetic lineations of spreading nature.

In order to look into the nature of magnetic anomalies, the correlation relationships between the magnetic field and bottom topography, surface of acoustic basement and types of magmatic complexes of seabottom were made (The main, 1978). As a result of analysis was established that the origin of this anomalies may be connected with the intrusion of basalts, andesite-basalts, andesites and their deep analogues. The intrusions and modifications of volcanic complexes are generally directed by affecting of the fault zones of different orders.

The levels of induced and remanent magnetizations of different rocks obtained at the dredging and drilling were measured. In addition the magnetizations of main type of igneous rocks against the temperature were determined.

The obtained data are following. The magnetization of Cenozoic basalts of Ulleung Basin is (2.56-5.73) A/m, and the value of remanent magnetization ranges from 1.35 A/m to 1.45 A/m. The level of this values is much lower if the absolute age of basalt increases, and it may regard that it is caused onto hydrothermal and metamorphous modifications.

The temperature against magnetization curves of basalts of south part of the East Sea (the Ulleung Basin and adjacent regions) are one-phase type with the Curie point of 260-295 °C ; to the north the Curie point of basalts of Yamato and Kita-Oki Arises reach the values of 550-575 °C. The samples of two-phase basalt group, in which both these interval took place, appear to be occurred here. In addition, practically all the rocks are stable for the residual magnetization.

According to the calculations of Yu. V. Shevaldin, which used the heat flow distribution, the depth of 580-790 °C isotherms are not the less of 10 km beneath the seabottom of the deep-water basins. The "narrow" anomalies of geomagnetic field (sublinear zones of 30-35 km width, the central part of which is the normal or lower values and its marginal parts are the high values) are related to the regions of large faults or fracture zones. In this case the length of longitudinal axises of anomalies reach the values from 30 to 150 km, the amplitude up to 400 nT.

Moreover, as it was shown, the connection between the higher heat flow of northern foot of the Yamato Arise and the present fault there, and Hansen et al. (1983) might explained that those regional negative anomalies were caused by a relatively shallow Curie temperature isotherm beneath the East Sea.

Taking into acount the region under study is situated near the young volcanic centres (the Ulleung and Dok Islands), and also sufficiently in the outlines of area of intersection of both seismic Line 1 and 11 where have been established the mantle uplift being characterized the high values of heat flow (not less of 90 mw/m^2) we may contend that the regional magnetic anomalies are caused by the undulation of the Curie surface the presence of volcanic rocks, which may be changed by the deep hydrothermal and methamorphic processes due to approaching to the seabottom the strongly heating materials of mantle.

5-3-2. Gradient Magnetovariation Sounding

In the points GMVS-1 and GMVS-2, two gradient magnitovariation soundings were made for the data of electric conductivity structure of earth crust. At the data processing the series duration of 55 hours in the GMVS-1 and 82 hours in the GMVS-2 (Fig.18) were used. The source series were filtered for the processing by the spectral analysis methods. The filtered series were considered as the realizations of stationary random processes, for which the amplitudes of variation spectrum for each pair of magnitovariation station were linearly connected:

$$dI_o(\omega,\varepsilon)=\tau(\omega)*dI_{\Delta h}(\omega,\varepsilon)$$

where dI_o and $dI_{\Delta h}$- spectral measures of processes at the two levels, ω-cyclic frequency, ε-element of elementary event space, index h - distance between the stations.

The calculation of spectral density was made by the method of smoothing of Fourier transform multiplications of corresponding source series so as the degree of freedom was equal 42 and the confidence interval of 0.8 probability was determined. The processing results are plotted in the (Fig.19) as a connection of k, ohm*m, (apparent resistance) against the $\sqrt{s}$.

The asymptotes "S" and "H", which determined the integral conductivity and conductor depth, respectively, are the subject of analysis. The asymptote S1 = 53000 S is related with the integral conductivity of sea-water layer (the sea-water specific conductivity ρ_k= 3.3 S/m) ranged between the level Hst = 560 m of station N2 and the sea bottom. The asymptotes S2, S3, and S4 determine the integral conductivity of geoelectrical section cut off from the left by the asymptote "H". Thus for the point GMVS-1 integral conductivity of high electrical conductivity zone at the depth of about 30 km is about

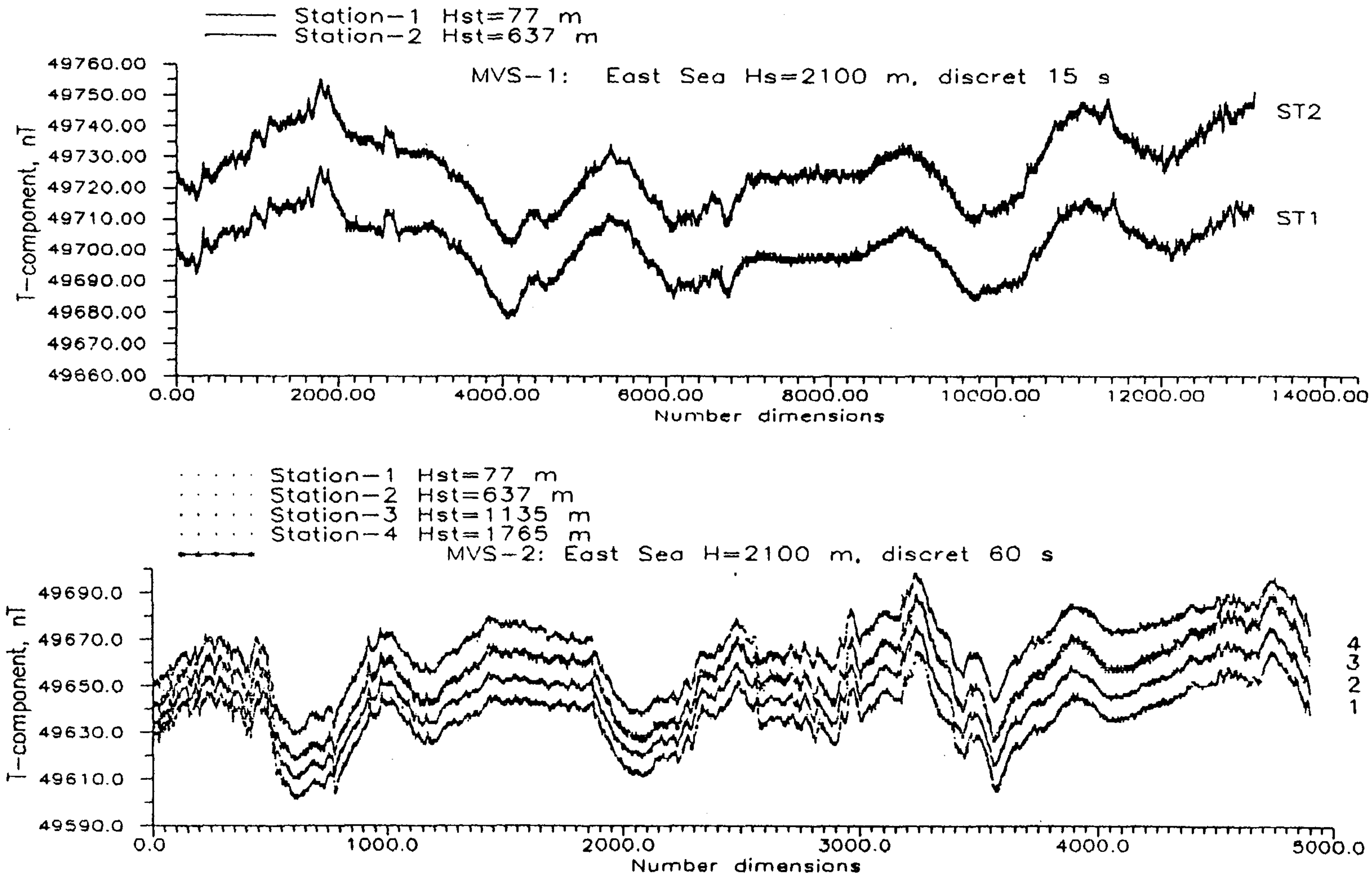


Fig. 18. The samples of magnitovariation measurements.

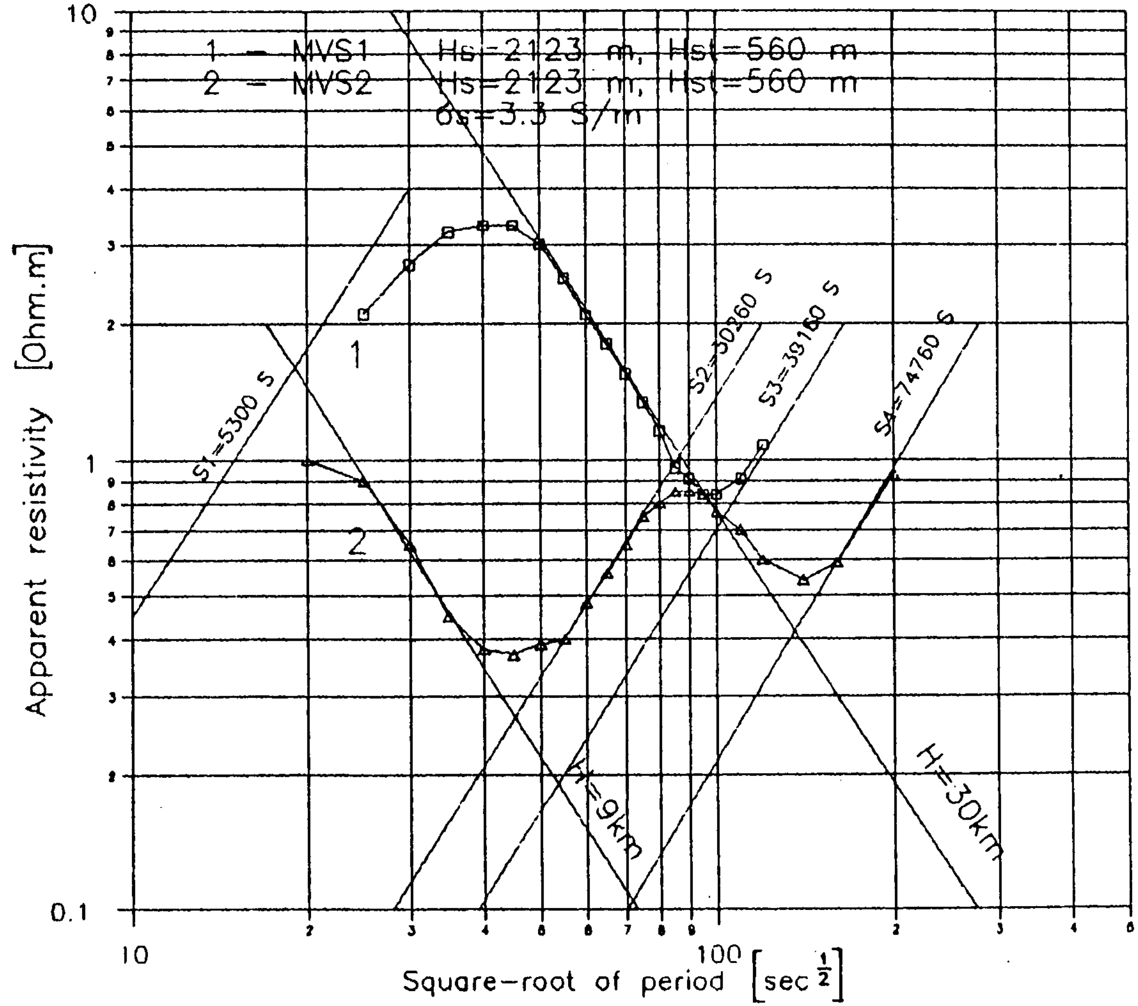


Fig. 19. The results of gradient magnitovariation sounding.

34000 S, for the point GMVS-2, where two high electrical conductivity zones at the depths of 9 and 30 km are distinguished , their integral conductivities are 25000 S and 39000 S, respectively. At the point GMVS-2 the level of roa minimum ranges in the limits of 0.35-0.6 ohm*m, and it mean the specific resistance of fluids not exceed these values in above zones; at the point GMVS-1 the specific resistance is not more than 1 ohm*m.

To find out the physical nature of these layers is a very important geophysical problem, for solution of which the complex of geology-geophysical investigations are needed. Using the known experimental and theoretical studies the physical state model of crust and upper mantle rocks may be proposed by the obtained electromagnetic data. It is known the crustal conductive layer is widespreaded in the regions with the increased heat flow and thickness thick enough of continental or transtional types. As it was first shown by Feldman (1976), the presence of crustal conductive layer is related with the fluids - over critical solutions, and conductive layer at the lithosphere - asthenosphere discontinuity - with the ultramafic melts.

In both cases the activator of processes produced these states of deep rock is the temperature, which is 400-500 °C in the crust and 1200-1400 °C at the lower lithosphere interface. The above temperatures correspond to the overcritical state of water and its highly-mineralized solutions with the specific resistance of not more 0.01 ohm*m, which are formed by high activity of water and its ability to dissolve both alkaline and silicate components of crust. The appearance of water may be caused by the dehydration of crustal rocks due to the activation of the reheating regime.

When the fluid concentration of the order of few hundred grams per liter under the normal conditions, the density decrease of water solutions after the warming-up is equalized by a pressure increase in the limits of the crust. Taking into account this fluid conductivity estimates and its volume concentration of 0.15-0.3% the thickness of first conductive layer at GMVS-2 is not more 2-3 km and at GMVS-1 not more 1-2 km.

The second layer at GMVS-2 is formed by a partial melting. Indeed by the experimental data the melting of basalt rocks may already occurs at the temperature of 700-800 °C in water presence whereas it requires the temperature of 1200-1400 °C in the absence of water.

Obtained experimental geophysical data allow to consider that the above proposed models are in accord with the nature of marked conductive layers. Note also the similar conductivity structures appear to occur at the rift zones and regions of volcanic activity.

5-4 The Geothermic Survey Results.

In the cruise, we made 17 stations of heat flow measurements (HF) it being from their : stations MG-40-13-16 was made along the profile I, stations MG40-3,5-12 along the profile II, stations MG40-4 between profiles I and II, MG40-7 on the south-west continuation of the profile I. The results of 17 successful stations are summarized in Table1and demonstrated on (Fig. 20). The various accuracy definition of H.F. was conditioned by the dispersion of the mean values of thermal conductivity of the piston core samples which depended on presence of tephra layers and other heterogeneous inclusions in the bottom sediments . Description of sediment cores are given in the present report. The new data are well corresponded to previous HF data for that region (Veselov and Lipina, 1984; Han et al., 1984 and 1985), although their comparison show that our data have 5-10% higher of

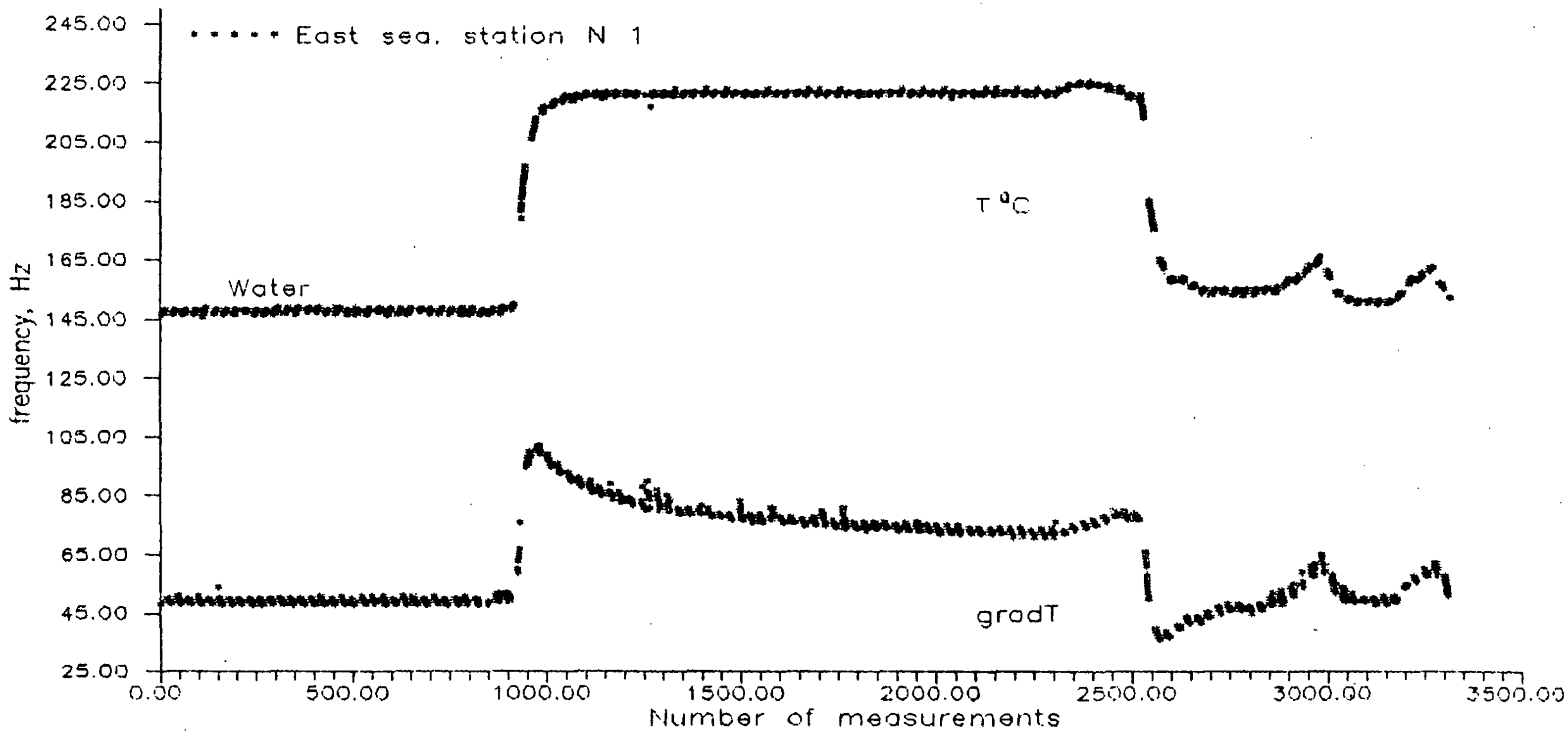


Fig. 20. The samples of heat flow recordings.

Table 1. Results of heat flow measurements

HEAT FLOW STATIONS

N.	Name	Latitude	Longitude	Depth sea, m	Depth pen., m	Gradient $K/m \cdot 10^{-3}$	Conduct. $W/m \cdot K$	H. F. mW/m^2	Err. %
01	MG40-01	36 31 0N	131 02.5E	2020	1.40	108.4	0.722	78.3	10
02	MG40-02	36 37.3N	130 54.5E	2120	1.85	139.5	0.826	115.2	20
03	MG40-03	36 46.0N	130 45.8E	2150	1.82	144.2	0.859	123.9	20
04	MG40-04	37 00.1N	130 46.2E	2140	2.40	99.3	0.727	72.2	20
05	MG40-05	37 00.9N	130 25.6E	2070	1.62	87.5	0.725	63.4	10
06	MG40-06	37 07.6N	130 14.4E	2030	1.95	83.7	0.895	74.9	20
07	MG40-07	37 15.6N	130 07.8E	1800	1.87	133.5	0.775	103.5	10
08	MG40-08	37 25.5N	130 00.1E	1450	2.49	144.2	0.736	106.1	20
09	MG40-09	37 36.3N	129 51.5E	1650	1.27	68.8	0.739	50.8	10
10	MG40-10	37 44.2N	129 45.5E	1820	1.58	73.1	0.742	54.2	10
11	MG40-11	37 06.8N	130 09.7E	2210	1.93	121.0	0.679	82.2	15
12	MG40-12	36 52.5N	130 36.6E	2080	2.01	144.2	0.779	112.3	15
13	MG40-13	36 49.9N	130 52.0E	2070	1.69	153.5	0.754	115.8	20
14	MG40-14	36 39.2N	130 36.4E	1960	1.43	125.6	0.764	96.0	15
15	MG40-15	36 24.2N	130 20.2E	1900	1.85	98.6	0.700	69.0	15
16	MG40-16	36 11.9N	130 03.6E	1520	1.96	118.3	0.735	87.0	15
17	MG40-17	35 53.6N	129 49.3E	900	1.83	101.4	0.756	76.7	15

Abbreviation: MG40-01 - cruis 40 R/V "Morskoy Geophyzik", number station of heat flow - 01.

the conductivities and lower of the temperature gradients.

Measurements of the bottom temperatures were made for all HF stations, their values are 0.26-0.27 C. The bottom temperatures of the Ulleung basin are practically equal the same of the Korean plateau in the limits of absolute measurement errors. The map of measurements is represented in (Fig.21). For the Ulleung basin limited by 2000 m isobath to the north and 1000 m isobath to the south data of HF are represented by 26 values, the mean values are 93 +- 8.2 mW/m^2. In the limits of 2000 m isobath - 17 values, the mean values are more higher - 97.8 +-9.8 mW/m**2 here. The dispersion of mean values was received by the Student coefficient with the calculus of probability equal to 0.9.

The central part of the Ulleung basin, in the region of intersection of profiles I and II is represented by the anomaly of HF ranged from 115 to 124 mW/m^2. Surrounding district of that anomaly have HF range of 80-90 mW/m^2. In the Korean Plateau there are two values of "normal" HF - 51 and 54 mW/m^2 and two values of high HF - 103 and 106 mW/m^2. First couple is rather like for borehole data near coast of Peninsula at the same latitude, and it may concordant to the stable structure as well as the arises and ridges where another couple is typical for tectonic process which are predicted at the trough structures of the Korean Plateau. Really in this case the high values of HF are coincided with depression zone or volcanic subbottom mound or active fracture zone (FZ1) while the low values of them may characterize the Wonsan Plateau (Fig. 11, 21).

No correction for sedimentation, surface and basement topography have been applied because this report puts emphasis on presenting data. However, the effects of this factors are of course not negligible in the general outline. They will amount up to 30% in the regions with high sedimentation rate and rough topography.

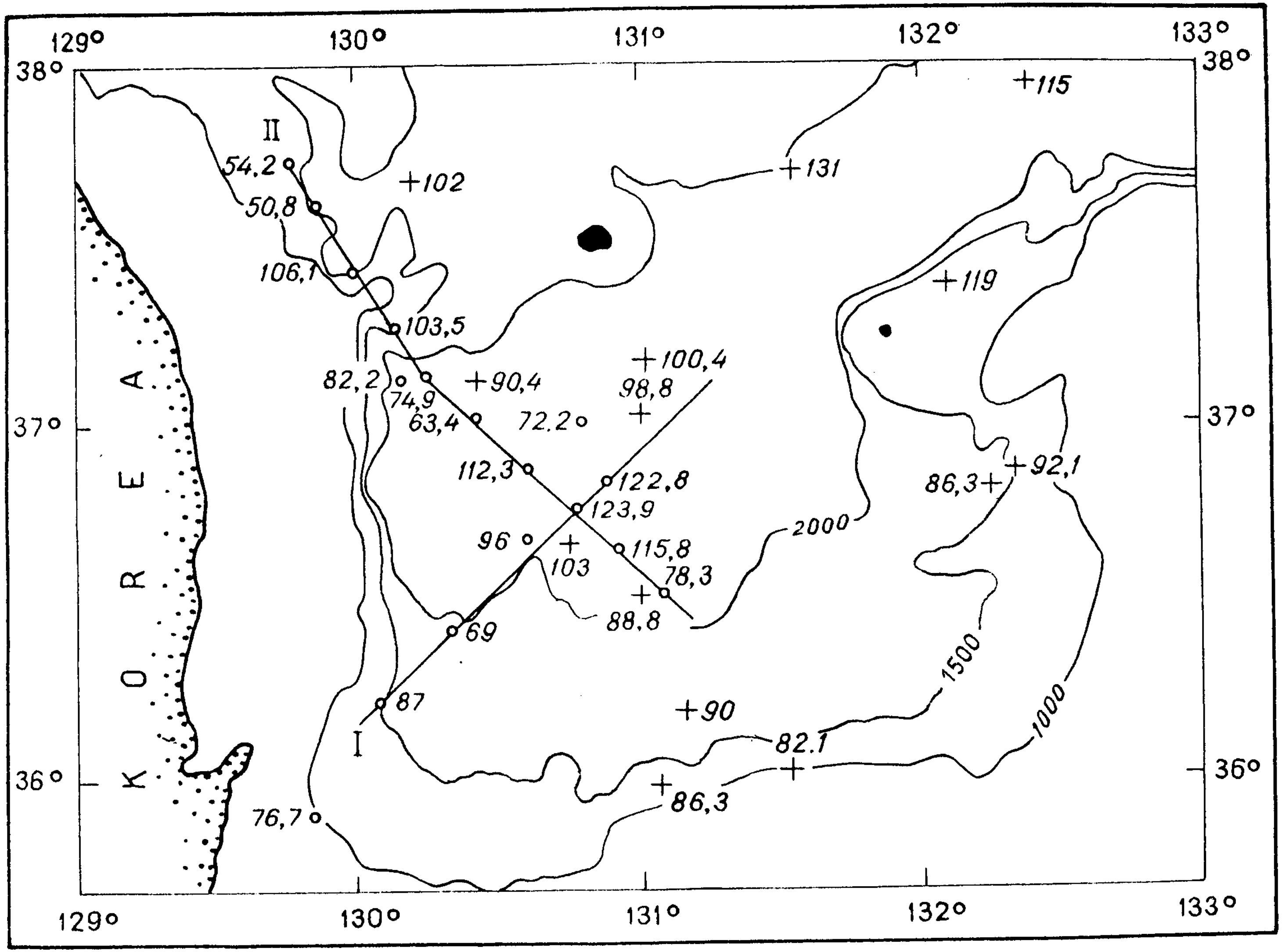


Fig. 21. Location of heat flow stations and their values.

Consequently our data of HF have lower limits of possible values.

For preliminary estimation of lower edge position of magnetic bodies and thickness of lithosphere the depths of isotherms 600 C and 1200 C, accordingly, were calculated along profile II in the Ulleung Basin and the Korean Plateau as a solution of stationary equation of thermal conductivity with the heat sources. Considering the similar geological evolution of both the Okhotsk and the East sea Earth's crust the model of radioactivity elements U, Th, K distribution was taken by the experimental data for rocks of the Okhotsk sea (Veselov, Volkova,1981). For continental and oceanic types of the Earth's crust of marginal seas the models of radiogenic heat sources are as follows :

Rock	Velocity,km/s	Conductivity, W/mK	Heat production,W/m^3	
			ocean	continent
Sediments	1.8-2.2	1.2	0.75	1.13
	3.0-3.5	1.8	0.75	1.13
	3.8-4.2	1.9	0.7	1.19
Diorite, andesite	5.6-6.5	2.1	1.3	
Basalt, gabbro	6.25-7.40	2.3	0.46	
Ultramafic	7.3-	2.8	0.013	

In the calculation of the temperature the crust of the Korean Plateau refer to the continental type, but the crust of the Ulleung Basin - to suboceanic type. The position of 600 °C isotherm under the Korean Plateau is estimated at the depth of 30-35 km, under central part of the

Ulleung Basin - 12-14 km (Fig.11). The main distinguishing feature position of isotherm 600 °C are corresponded to main character of magnetic field on the bottom surface. The temperature of 1200 °C under central part of the Ulleung Basin are reached at the depth of 25-27 km and are corresponded to the depth of position of high electroconductivity layer obtained from the cruise magnetovariation sounding data (see above, 1V-3.2).

5-5. The Crustal Structure of the Korean Peninsula

The evidences around the Korean Peninsula crustal structure are significant a bit. The very shorten references of data published by the Geology of Korea (1987) are only known up to date. From those evidences the Korean crust of the Earth was calculated on basic gravimetric measurements and was estimated about 35 km thick. This value well coincides with same one obtained from data of the earthquakes. The one of these attempts are published by K.W. Lee (1979). Besides the analyses around the regional isostatic anomalies of the Korea Peninsula have been made. This results showed that considering the gravity-topography relation the south Korea is in isostatic equilibrium expect to southeastern part where the maximum isostatic anomalies reaches values up to 35 mGal. Those features are explained by been related to the high heat flow values of the area and probably causes of the low velocity mantle zone which may be predicted by the seismological results under the southeastern offshore of the Korea Peninsula. And from this view of points it is very significant interpretate the narrow relative high (more than +60 mGal) gravimetry and magnetic residual (from -160 nT to +240 nT) anomalies offshore Pohang Area. According to the cross-sectional model of the

Geyongsang Basin proposed by Min K. D. and Chung C. D. (Geology., 1987) the explanation of those phenomena are possible in the term of uplift crystile granit-gneiss strata as well as a big intrusive complex are locating on the junctive bondary between crustal Korean structure and crustal Ulleung Basin structure and due to the existence here the powerfull Tsushima-Goto Fracture Zone.

5-6. Deep Crustal Structure of the Ulleung Basin

The structure of the crust under the Ulleung Basin by using refraction OBS data have been conducted on two investigative lines Line I and Line II (Fig.10,11).

The maximum distance which defines of the depth study in this methods was reached about 110 km. However this distance is not sufficient to define the type of crust because (Pavlenkova,1982) to reseach the real crustal structure it's need to have more length of the record-distance attaining around 400 km onland and around 200 km on the sea. The strong believed first arrival break due to Pn-waves reverse the background of the fitting noise-signal ratio is not always possible. On the base those results the prelimenary model of the crustal structure by using Seis-83 (Ray Trace Method) computer-program (Cerveny, Pcencik., 1983) have been realised. And so if the received seismic models of the crust of the Ulleung Basin are came true it is possible to formulate the principal considerations in follow after an any previous remarks.

Before it's need to point out that the Earth's crust of the Ulleung Basin are closely similiar to those of the Yamato Basin in the term of the thick, boundary velocity of Moho-discontinuety, layering and composing by two velocity-structural floors. First of those it's sediment cover and other - crystilline part (the continental type of the basement ?) which are conspicuous concorded with topmost of the crustal structure of Korea Peninsula (perhaps Kyushu Island and other Japan islands also). In another side the velocity distribution along lowest boundary since the top boundary Unit 111-1 and Unit 111-2 and until the Moho-discontinuety inclusive are kept the influences from volcanic and intrusive processes. Furtheeover, there are close correlation between the geometry of the Moho-boundary and the inner structure of sediment cover. However it's seems to come true that the actual location on the depth scale and geometric of Moho-discontinuety are holded by the newest geodymamic movements until sediment cover preserved the tracks of the ancient geohistory. In any cases the gravymetric high anomaly zone which have been recognized on the most deepest area of the Ulleung Basin are seems to cause uplift of Moho-discontinuety.

On the base of the speculation over the crustal structure of the Ulleung Basin above it stood to understand that location of the volcanic Ulleung-do and Dok-do Islands were caused by transections of the Fault Systems of Korean trends including of the extending buried ridges looked out above.

5-6-1. Line I

As the sediment cover structure was presented above the consideration of the Earth's crust structure of the Ulleung Basin carry out in the term of its the deepest path only (Fig.10).

The upper boundary of the crust is ussually the surface of the geologic basement (or the surface of the crystalline crust) which in this aspect are the interfase discribing by the velocity characteristics in value range from 5.54 km/s near onland and shelf to 5.7-5.95 km/s on the central part of the Ulleung Basin.

The depth of bedding of this discontinuity vary from 4.9 km near on the continental slope to 7.5 km over the central deep part of the Basin.

As mentioned above (see, 1V-2.4) the composition of the strata controlling by this interface were affected from the methamorphic transformation caused the uplifting of the heating mantle mass. It seem that this declaration by the changing of velocity under boundary beginning from the area north-oriental the FZ-2 zone (Fig.10).

Below this interface are predicted the strata in which exists the gradient velocity that expenses to just enough closely the Moho discontinuity. However, it's been established that this depth are separated at least on two horizons. The uppermost of them have the most value of gradient which may be estimated by (0. 07 -0.1 km) in the layer of (1.5-3.5) km thicks until in the middle and the lowest part of the (8.0-12.0) km thick strata the velocity gradient not amount up to much(less than 0.005 km).

The thickness of the Earth's crust along Line 1 vary from 21-25 km on the southwestern edge to 15-17 km on the northeastern one. The biggest part of the seismic cross-section are characterized by the relatively shallow bedding of the M-discontinuity which not amount up 16 km including the depth of seawater. This situation are very good coincided here with level of Bouger anomaly.

The velocity of the head wave extending along M-discontinuity vary from 7.93 km/s under the Ulleung-Dok Islands volcanic area to 8.0-8.16 km/s under non-volcanic parts of the Line.

Below the the bottom of the crust (M-discontinuity) the refracting medium are attributed relatevily a small velocity gradient (not more than 0.05-0.08 km) and on the depth around 25-35 km will be changed due to the existence of the thickening Low Velocity Zone

(LVZ). The same declaration are corroborated by magnetovariation measurenents (see above, 1V-3.2 B) and the seimologic exploration (Abe and Kanamori, 1970).

5-6-2. Line II

The structural features which have been revealed along Line II are just closely similiar to that of Line I. However there are the several distinctions caused from the seismic cross-section(Fig.11). The boundary which was defined above in the term of the geological basement or the roof of the crystaline crust or the top of third ocean layer are attributed here by velocity variations from 5.4 km/s on the Korean Plateau area (the northwest wedge of Line) to 6.3-6.4 km/s over the uplifting M-discontinuity.

The transition high-gradient layer discribing above have been established here only over the eastern edge of the Line II. The values of these gradient closely similiar to those of the Line I.

However the northwestern half of the cross-section are characterized by the differ construction of the crust. As follow from Fig.11, the western from the FZ 1 the distribution of velocity inner crust are pointed up the typical continental values and between both the FZ 1 and FZ 2 the velocities are coincided to transition zone from continental structure of the Korean Plateau to suboceanal one of the Ulleung Basin.

The Moho-discontinuity beds here on the depths from more than 21 km under continental slope of the Korean Plateau to 15-16 km under the eastern edge of the Line II. The velocities of the head wave are not distributed along this interface as uniformly. Over the western half of the cut and over the eastern edge the values of velocities mean not more than 7.8-7.9 km/s until over the maximum of the upwarping of Moho-discontinuity these values reach to 8.16-8.21 km/s. And what is more the gradient of velocity stand here more than 0.06 km.

One of the different feature from same of the Line Ⅰ there are here the revealing of the High Conductivity Zone (HVZ) over the depth about 10-14 km, i.e., inner crust. This HVZ are situated nearby and along FZ 1 that may be evidented about active tectonic life being tied with hydrothermal convective reheating of rocks and volcanic influences.

The thinning of the lithosphere have been told above (Line Ⅰ) represented here by the second High Conductivety Zone (HVZ) situated on the 25-28 km depth.

5-7. Final Remarks

The topmost of the crustal structure of the Ulleung Basin is liken with that of the Korean Peninsula until the lowermost of its is more similiar to that of the Yamato Basin. The principal features of the crust hold the tracks of ancient geohistory and the newest geodynamic processes. In the view of points of received results around the crustal structure of the Ulleung Area cannot be inferred from the plate tectonic pattern.

However in another side the comparison of the velocity distribution over both Line each other are revealed that on the intersection areas the velocity of the whole crust scale are sufficiently more over Line Ⅱ in this respect to Line Ⅰ. Best known that same relation (quasianisotropy) are usualy coincided to the narrow tectonic zone of the extension.

CHAPTER 6

RESULTS OF SEISMIC RESEARCHING ON THE OFFSHORE AREA OF THE KOREAN PENINSULA BY REFRACTED WAVE METHOD

CHAPTER 6. THE RESULTS OF SEISMIC RESEARCH IN THE OFFSHORE AREA OF THE KOREAN PENINSULA BY REFRACTED WAVE METHOD

6-1. Introduction

Detailed seismic survey conducted in the eastern offshore of the Korean Peninsula by Huntec LTD (1968) Schluter and Chun,(1974) revealed the fine structure of sediment cover (Fig. 9) which overlies the complex strata of the acoustic basement and constitutes at least three deposit-rocks Basins (Pohang, Hupo, Mukho). These sedimentary basins extend parallel to the eastern coast of Peninsula being separated by the narrow transversal inter basin rises. The thickness of Tertiary is seems to be about 1400 meters and the sediment cover was folded and faulted producing variable kinds of an anticlinal and a synclinal structures probably associated with the drift movements during an opening of the East Sea (Yoon and Chough,1992).

Based on the research of adjoined mainland area, the acoustic basement underlying the sediment sequence is represented by metamorphic rocks of the Cretaceous ages which were often being intruded by the gneiss and granite rocks. The composition of this acoustic basement has been established by the drilled boreholes on the land, by investigating number of exposures and by seismic refraction survey. From these results the Tertiary sediments (the thickness about 800 meters) was characterized by velocity of about 2.05 km/s until the Cretaceous agglomerate and tuffs attribute the velocity of about 4.7 - 4.9 km/s. Besides in many cases the older Tertiary consolidated sediments have been also defined and their velocity characteristics were likely fit up to values of about 3.0 - 3.5 km/s.

Also there established that the acoustic basement mapped reflected wave method may have to be shown in Pohang Basin as the varying from place to place rocks. In the northern part of this Basin the basement is presumably represented by granite or and the metamorphic strata until in the southern part of the weak reflections which were difficult to correlate have been recorded beneath the top of it (Schluter and Chun,1974). In this case the acoustic basement at least on the uppermost are represented by the consolidated normal-sediment strata of older Tertiary ages.

6-2. Materials and Method

An offshore refraction research cruise was carried out in the Pohang and Hupo sedimentary Basins during the last cooperative (KORDI-IMGG) expedition. Two refraction Line (III and IV) using OBS's and big air-guns (Fig.4) has collected in the continental shelf and slope regions aiming to investigate the acoustic basement nature underlain the shelf and the deep basin areas.

The techniques of thoese study are just enough similar to that which IMGG were being realized on the eastern Sakhalin shelf. The same method best known may have the truthful results as well as the tools for researching of the second the lowest structural strata. Usually this structural floor is a main non-layering and strongly metamorphic sequence nor has being the possibility to study it by reflected wave method.

In this case by reflected data the top of this sequence are established as the acoustic basement being included the more-consolidated strata but with occurrence of the sufficiently sedimental nature bases.

Both Line (III and IV) have four and five positions of OBS. The range of Curve Travel Time (CTT) of every OBS-records are fit up 30 km (Fig.4) and consisted of four main branches of refracted waves:

1) the refracted wave into the uppermost a mainly horizontal stratification and thinness of the normal sedimentation section of the upper Cenozoic strata. The velocity of this sequence varies from 1.55 to 1.9 km/s. The maximum spread of the first branch is less than 5.0 km;

2) the refracted wave extending into the older Tertiary sediment strata which is being characterized by velocity of about (3.0-3.6) km/s and thickness range from 0.4 km on the uplift part of basement to 1.0 km on the axes of the sedimental Basin;

3) one of the principal part of the CTT is attributed to the refracted wave describing the velocity range from 4.5 km/s to 5.6 km/s and are followed up to the spread about 20-25 km from OBS locations. This pattern may have to be reached concerning occurrence of the thickness and distribution of pre-Tertiary (mainly as Cretaceous of ages) strata in Pohang Basin. The head wave velocity along the top of the Cretaceous sequence are about (4.7-5.0) km/s and coincide to those of which have been penetrated as the Upper Cretaceous agglomerate and tuffs onshore near Pohang area.

4) the far second half of CTT (at the distance about 18-30 km from OBS-location) as a rule are described by the apparent velocity range from 5.5 km/s to 7.0 km/s which apparently was being tied to the top of the most ancient rock seams. It seem true that this strata are really the ancient geological basement of the Korean Peninsula and offshore regions.

The preliminary results following from up-to-date seismic survey display that the surface of geological basement varies from place to place as the values of depth where it were met (1.0 - 2.5 km) and so the values of velocity which were attributed (5.4 - 7.0km/s). Those variations testify the change of ages of rock : the mainly older (the velocity more or equal 6.0 km/s) on the north (Hupo Basin, Line 1V, Fig.22) as Proterozoic and the apparently younger - on the south (Pohang Basin, Line 111, Fig.23) as older Mesozoic (the velocity equal or less than 6.0 km/s).

It seems very important to regard that over the Pohang Basin area the acoustic basement contains the older Tertiary sediment rocks (Yoon and Chough, 1992) and geological basement are younger relatively to that of the Hupo Basin.

6-3. Discussion of Results

The summarizing of all available seismic data including the published (Huntec LTD, 1968; Schluter and Chun, 1974; Yoon and Chough, 1992) and experimental evidences allow to formulate the principal results which may have to estimate the geological structures of the Hupo and the Pohang Basins with respect to update received velocity characteristics of their stratigraphic boundaries.

6-3-1. Line 1V

Thus the seismostratigraphy of the Hupo Basin structure displays that the previous conclusions assumed by (Yoon and Chough,1992) about the shifting of axes of deposit basin from the west to the east are taking place. The axis of the maximum depth of the youngest sediment basin coincides with the area of point "10 km" (see Fig.22). The Quarternary and younger Miocene sediments are described by velocity less than 1.6 km/s. In this way the occurrence of

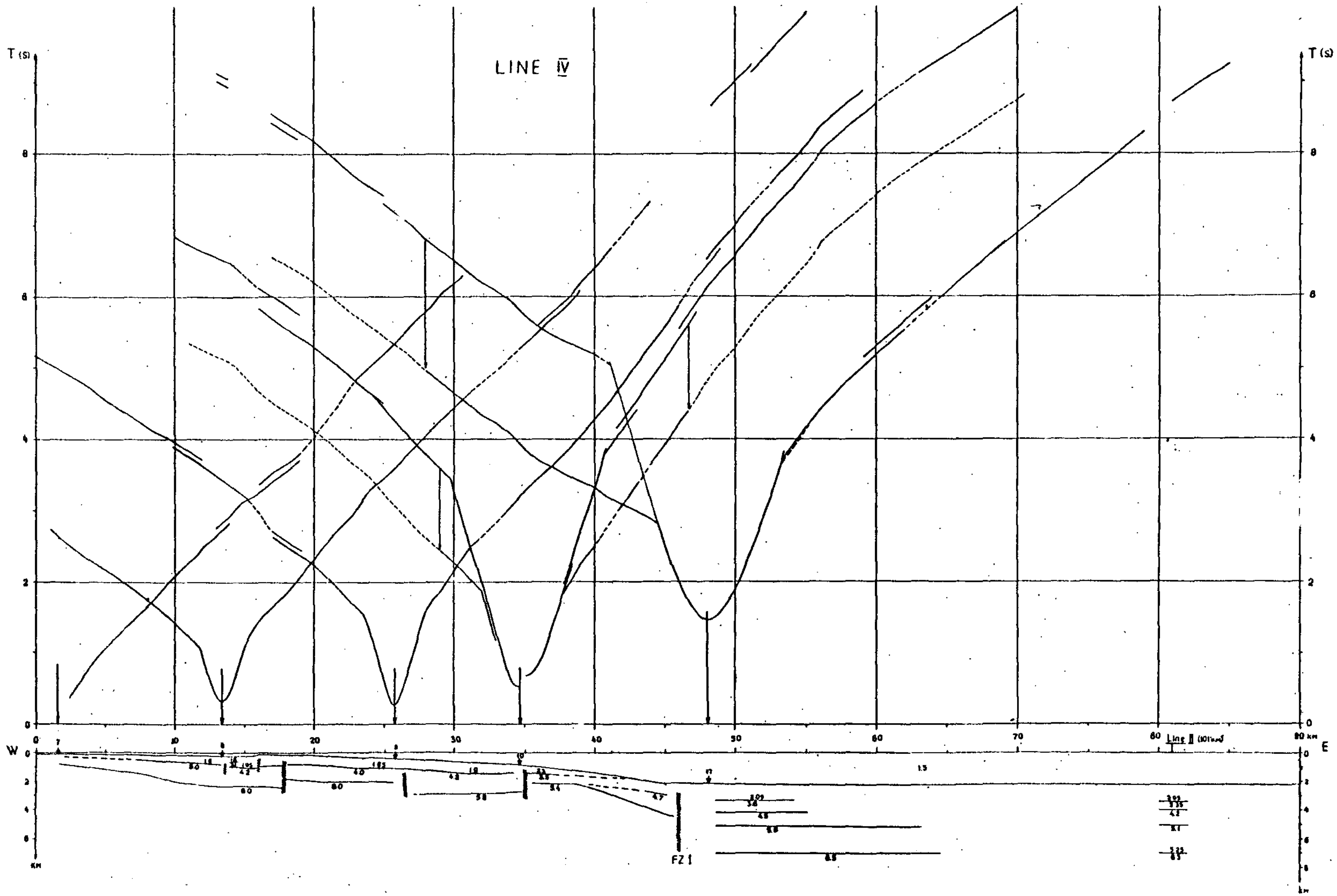


Fig. 22. The travel times curves and cross-section of Line IV.

Key : see Figs. 23,10.

velocity with more than 1.6 km/s value into the uppermost of sediment cut are the proof of the existence in this layer else older deposits.

The maximum of thickness of those fit out well to 0.8 km near on the location of OBS-8, i.e. near on the eastern border of the Hupo Basin (point "14 km", Line 1V, Fig.22). The oriental from this point and to the eastern edge escarpment of the Hupo Basin (around point "18 km ", above) the narrow (14- 18 km , at Line 1V) local sediment zone has been established where the older Tertiary deposits (velocity about 3.0 - 3.6 km/s) underlain the Quarternary. Thickness of these deposits is less than 400 meters here.

Over the Hupo Basin area(occidental point "18 km", Fig.22) the Cretaceous strata which has characterized by velocity range from 4.2 km/s to 5.0 km/s underlain immediately the Quarternary. It seems so the thickness of the young Tertiary here very than or absent, they are not evidently revealed by the refraction method.

Thickness revealed Cretaceous deposits appears to be about 0.8 - 1.5 km . However according to (Geological, 1984) it may be shown that this strata would have another ages because the Hupo Basin has been situated in the tectonic zone with an outcrop of the Paleozoic or more older geological basement in respect to southward.

The Hupo sediment Basin was separated from the continental slope and the Ulleung Basin by the Hupo Rise. The geological basement of this tectonic uplifting is represented by horst-anticlinal elevation of the strata in which the velocity are about 5.8 -6.0 km/s and the ages are not less than Pre-Mesozoic.

Over Line 1V (Fig.22) the seismostratigraphic construction of the continental slope are described by set of the interface velocity which have been strongly coincided to those of the Hupo Basin and Hupo Rise in the uppermost of section. But over the deepest level of this cut it's possible to show that on the oriental area from point "35 km"(Fig.22, OBSs-10) the boundary with velocity of the most than 5.8 km/s (the strata of Pre-Paleozoic ages ?) is not established because the recorded length of CTT is just short with respect to its need.

Furthermore the far oriental the deep and powerful fracture zone (FZ1) have been pointed out which separate the continental style of the Earth's crust of the Korean Peninsula borderland from the crust style of the Ulleung Basin. It seems evidently that this fracture zone are young because set of seismic boundaries are very similar to set of velocities in the continental slope offshore of the Korea(the range between point "35 km" and point "45 km",Fig.22).

In this case, the crucial evidences on the understanding of geological situation follow here on base of path of cut-section between point "26 km" and "35 km"(Fig.22). This block containing the full set of geological seems with sufficient sediment nature and ages from Pre-Paleozoic to Early Miocene have been strongly intruded by volcanic rocks. The last sentence means the growth of the velocity values toward from the western block to eastern one.

6-3-2. Line 111

The seismostratigraphic structure of the Pohang Basin and the northeastern ward 120-km trend of Kuryongpo Peninsula are very similar to that of Line 1V.

If we compare with line III and IV will be realized, the common features may be revealed. The main pattern of these structures is basement escarpment (Fig.23 ,it's named as FZ1) which may be traced over a distance of 110-120 km northward from Line 111 to Line 11. It can be represented as the deep fault zone named (Yoon and Chough, 1992). It is evident that both faulting lines Hupo and FZ1 are confidently constructed framework caused by their parallel trends each

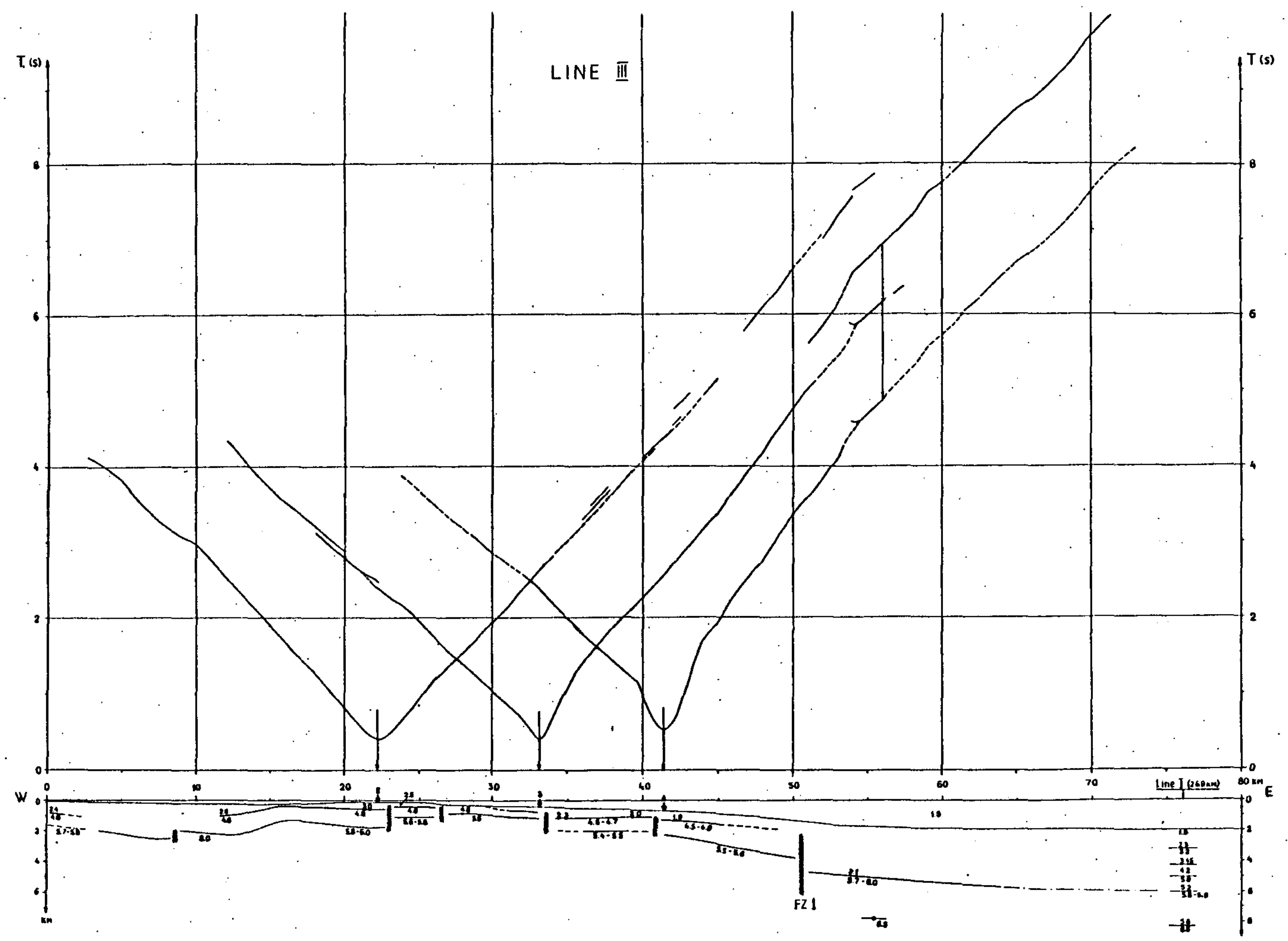


Fig. 23. The travel times curves and cross-section of Line III.

Key :-travel times curves, see the others in Fig. 10.

other and simultaneously to the eastern coast of the Korean Peninsula (Yoon and Chough, 1992; Fig. 10, p.36).

In another side this framework of fault-fold system are affected by the Yangsang fault zone (YFZ) which intersection may be situated near on the location of OBS-8 of Line 1V (Fig.22). If it's true, both the Hupo and Pohang Basins have been separated by this powerful fracture zone.

According to the means above the fine structure of Pohang Basin may be represented as follow.

The description of the structure of the Pohang Basin along Line III are being presented from the west toward the east. Line III begins near the east coast of the Korean Peninsula where water depth of the sea is less than 60-80 meters. Here the uppermost of the seismic section are compared to Quaternary and the Early Tertiary(Early to Middle Miocene) which had been drilled onland near Pohang. As the velocity in this layer means at least two sequence, it will be useful to estimate thickness of lower (apparently Early Miocene strata) seam due to calculate (the same technique are best known in seismic exploration. The initiative values are: velocity in Quaternary is about 1.6 km/s; velocity in Early Tertiary-3.2 km/s; total thickness-0.8 and 2.0 km) of average velocity technique. According to those account the thickness of the Early Tertiary may be predicted on the west side about 0.5-0.7 km

and over central part of the Pohang Basin about 1.4 km. Considerably that the eastern border of Pohang Basin are apparently situated over point "15 km" where stratified sediment become very thin and may be failed.

As being declared by (Yoon and Chough, 1992) the sediment strata are underlain by the acoustic basement which is characterized by either fairly-stratified reflections or non stratified, opaque reflectors.

Inland, near Pohang this complex series defined by refracting method was coincided with velocity range from 4.7 km/s to 4.9 km/s and confronted with Precambrian metamorphic rocks and the Cretaceous granitoids being exposed also in the adjacent (of the Pohang area) coastal areas.

However as follow from previous refracted exploration over the south off Pohang Basin the velocity of 4.4 km/s value is attributed to rock complex horizontal layering assumed and named as layer 3. This Upper Cretaceous sequence represented evidently by aglomerates, andezitic conglomerates and tuffaceous sandstones (Schluter and Chun,1974) are underlain by crystalline rocks(apparent velocity 6.3 km/s) at a depth of 1.9 km to 2.0 km and it is represented as means by granitoid or highly metamorphosed rock complex.

On the basis of this layer with Head Wave velocity 4.6 km/s are looked out as Upper Cretaceous deposits the maximum thickness of which have been established at the central part of the Pohang Basin (near point "10 km",Fig.23) fitting up to 1.5 km.

According to Schluter and Chun(1974) ; and Yoon and Chough(1992) the boundary with velocity (5.8-6.0) km/s are coincided here with the Precambrian rock complex consist of granitoid and metamorphic series.

Input updata refracted results may be assumed (Fig.23) that both seismic interfaces (velocity 4.6 km/s and 5.8-6.0 km/s) are to be mainly concordant and the Pohang Basin have been formed as continental margin off Pohang-Youngdouk inland Basin prior to Middle Miocene.

The deep fault zone in the central part of Pohang Basin(Fig. 24.) was defined the development of fault-fold structure inner Cretaceous strata. May be it had produced the conditions for buckling and fishing on the border area near on this fracture zone. The evident decreasing

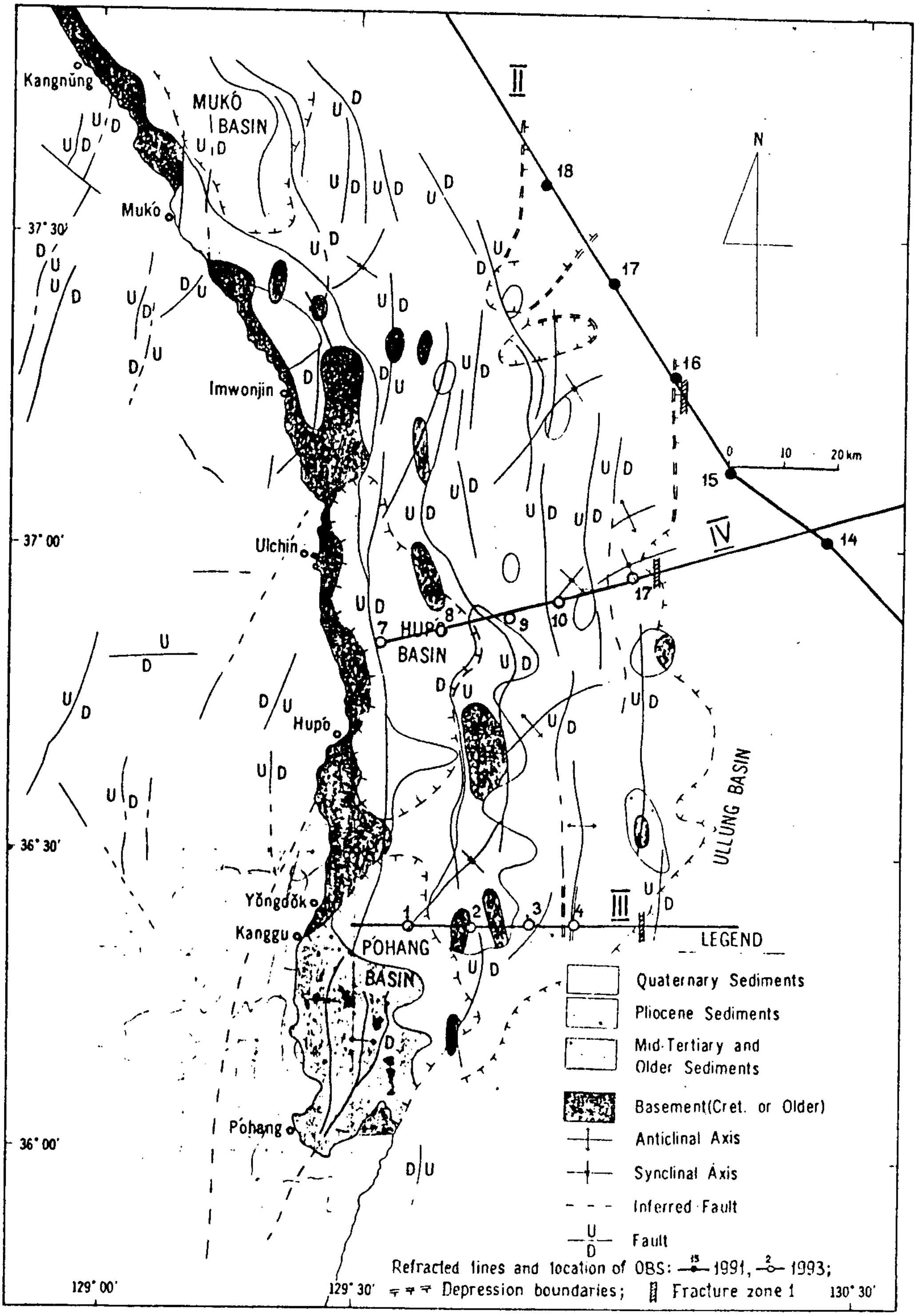


Fig. 24. Tectonic map of the oriental offshore of Korean Peninsula.

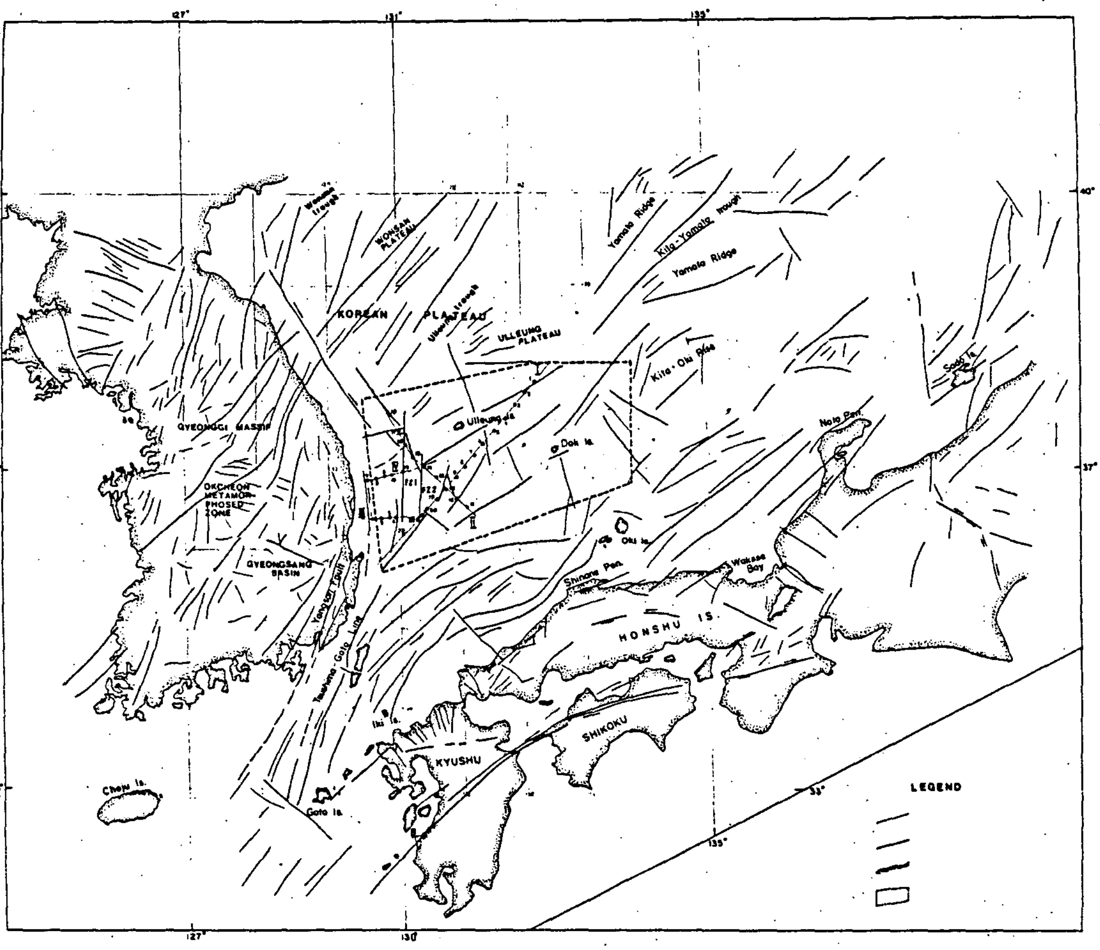


Fig. 25. The tectonic features of Korea Peninsula and surround areas of the East Sea compiled by using the Geology of Korea (1987), P.Kang (1981), S.Chough(1983), E.Inoue(1982), H.Gnibidenko(1979), S.Lalleman and L. Jolivet(1986), Huzita(1980), The Geological Maps of Japan (19 Russian) and N.Niitsuma(1988). The legend:from top to low main lineaments,faulting zones,coast line, outlines of studies area of the Ulleung Basin.

of velocity of this layer with respect to that inland and progressively extending the marine depositional environment on the seaward from inland(Geology., 1987) strongly suggests that this stratigraphic sequence may have the oil-gas potential as in the Japan(Hokkaido Island; Yamazaki and Tanaka,1993) and that overlaying Early Tertiary unit have possibility of another oil-bearing areas around the West-Pacific margin.

The elongated ridges early (Schluter and Chun,1974) named as continuity of Kuryeongpo Peninsula which was faulted (Fig.3) by Hupo Fault Zone (HFZ) are confirmed.

On the level of boundary with velocity 4.6 km/s and its underlain boundary with velocity of(5.6-5.8) km/s, this structure are represented the complex tectonic coffer-shaped anticline-belts extending on the northeastward as well as trend of the above presented buried ridges(1V-2.3). In this case the northeastern edge of this structure are truncated by the Fracture Zone 1 (FZ1; Fig. 22). However this situation are not interrupted to be correlated the seismic interfaces from Korean shelf and continental slope to inner of the Ulleung Basin.

6-4. Conclusion

The detailed speculative consideration about tectonic movements on offshore of Korean Peninsula have been provided by (Yoon and Chough, 1992). The new refracted data are not confronted to these and only pointed out that the opening model of the East Sea proposed on base of those results are apparently bad concurred with them.

There are many strong and real geologic and geophysic evidences which must contradict to the prior model construction. The main of them besides another looked out above there are crucially extending of the shelf ridges and folding structures to inner of the Ulleung Basin preserving the northeastern trend with a bit clockwise rotation. The fracture zones as FZ1, FZ2 and Hupo Fault are pointed out on the their rejuvenation from the the East to the West having clearly reservation of the actual coastal direction.

CHAPTER 7

TECTONIC PATTERN

AND

EVOLUTION

CHAPTER 7. TECTONIC PATTERNS AND EVOLUTION

7-1. The faulting Pattern and Tectonics

The tectonic patterns of the East Sea (Sea of Japan) based on the compiling of the full available summarized evidences have been considered.

The principal goals of those constructions being always presented in terms of origin and evolution of the sea regions which is complex but similar, the marginal sea basin of the West-Pacific were proposed. In those cases the mechanisms of the origin and formation have been usually suggested before the analysis of the tectonic patterns. However among those only a few proposed constructions may have to put up as the basement of following speculations.

In any case the extending seaward from the land structures of the Korean Peninsula are really crucial evidences on the tectonic patterns of the Ulleung Basin and contiguous vicinities.

Before any time H. Gnibidenko (1979) have been assumed the extending of most of the Korean Peninsula structures seaward to Japan Sea bottom as well as the geosynclinal systems which had been emplaced as enzymatic geosynclines in the Early Paleozoic and Precambrian times. The deep geosynclinal basin of the Ogcheon Neoand Paleosynclinal structures were as his viewpoint constituted the floor of the Japan sea in terms of the contradiction with rifting and subsequent sea-floor spreading for this region as well as submarine margin of the Sikhote-Alin and Korean parts of the Asia continents.

The continental structures extending to the continental and island slopes have been considered by I.Bersenyev and

V.Bezverkhny(1988). At last the Geological map constructed on the basis of the results of numerous dredged study of the submarine rises, ridges and highs and continental slopes had been published in 1984 (Geological Map, 1984) The southern and east-southern parts of the Ulleung Area was studied using geophysical survey and results of deep boreholes which revealed that the present shelf off San-in Area northeast of the Tsushima Island is underlain by a thick (more than 4,0 km in thickness) Olygocene and Miocene sediment sequences. It was pointed that lowermost of this cover had been deposited as well as progressively northward deeping basin was being developed in early Miocene. In any words the Ulleung Basin area was situated in terms of fulfilled deepening basin since later Olygocene to the early Miocene.

Furthermore the late Miocene faulting blocks on the eastern shelf off Honshu and Korea strait have been also established as well as crustal deformation occurred over the peripheral areas of the Ulleung Basin including the buried ridges of its inner region (which are indicated above) and the same as been revealed underlies the northern Honshu shelf (Chough, 1983). It seems necessary to point out that the trending of most principal structures fixed on offshore areas and associated with those of land (faulted and folded blocks-zones) are arisen in the NNE-SSW,NW-SE,and WNW-ESE directions(Kang,1981) and also coincided with the best known faults expressing as 5 strike-slip type (Yoon and Chough,1992).

Those last systems are just well studied on the Korean Peninsula and the adjacent southeast vicinity (Inoue, 1982). They predominantly define the tectonic patterns of the Ulleung Basin.

From this means there are two dominant trends of tectonic lineaments in southeastern offshore of the Korean Peninsula which have been established here by geophysical and geological data (Kang,1981; Chough , 1983 ; Lew et.al.,1970 ; 1972 ; 1973 ; see also Chapter 4). The

Mesozoic tectonic movements was to be revealed as the strongest deformation in Korea caused by the Precambrian movements which had been activated essentially in southeastern of Peninsula. They had involved in those movements the nearby vicinity of the Ulleung Basin submarine structures (Yoon and Chough, 1992 ; Park, 1992).

The fault and fracture systems on the southeastern and southern areas of the Ulleung Basin where it's approached and connected to Honshu and Kyushu Islands are also well known(Huzita, 1980; Niitsuma,1988; Inoue,1982).

Thus, according to all available published data the map of principal tectonic lineaments and fault patterns have been compiled (Fig.25).

On the basis of those patterns the extendings of the Ogcheon Fold Belt, Yangsang and Tsushima-Goto Fracture Zones are evidently beeb settled. In the southern part of Ulleung Basin the fault systems have been fixed by original seismic,other geophysical and bathymetric data.

It seems to be indoubitable that there are two types of trends of the lineaments like the inland systems. The first of them is the trending in the NNE -SSW direction and extends on the Korean inland and on the Japanese Islands.

The other trends develop in WNW-ESE and NW-SE directions according to those of the Korean Peninsula which there are characterized by apparent left lateral movements. In this viewpoints the Ulleung Basin was situated in place as well as tranquil small scale shifting area but as triple conjugations of various trendings. However as shown above the structures of sediment cover of the Ulleung Basin were slightly folded only near the edge areas and over the Korean Plateau regions.

It seems to be clear that the Gyeongsang conjugate system of fold-faulting movements may have to extend toward the offshore area near by the sea-floor and the structure of Korean Plateau may have to constitute with that of the inland with respect to the right lateral shifting along the powerful northeastern Korean fracture zone (Fig.25). This means are confirmed by relationship between Mukho deep sediment basin and the Ulleung through including as a component of Korean Plateau.

From this viewpoint the Korean Plateau is the real continuation of the Ogcheon Folds Zone and the Yamato Ridge are suggested to coincide with the Korean Plateau on the NNE-extension.

Thus if it remarks that the central part of the Ulleung Basin had existed as deepest fulfilled basin since the ages of the Unit 111-3 above (about Late Cretaceous - Olygocene ages) until the structures of the northwestern Honshu (Shimane Peninsula) trends to Oki-Yamato Banks, the relative stable location of the Ulleung Basin may have to confirm on the basis of themself suitable and well determined evidences. However in other side the active tectonics developments and movements in the East Sea Area have been also fixed as the location of the Ulleung Basin and fracture zone distributions are shown.

It is necessary to add that at all the fractures and faulting zone are strongly separated by the ages of their formation as demonstrated in (Chapter 5.) when the shelf results was been discussed.

7-2. The Speculation on The Origin and Evolution

Evolution

To explain the formation of tectonic pattern looked out above the two principal group of mechanisms have been proposed usually as follow:classical back-arc spreading and the hypothesis of oceanization of the continental crust. The latest it's assumed a possible continuation of geological structures from inland seaward beneath the seabottom. Beside there are many intermediate and combined means of those problems. One of them is developed since I.Bersenev (1971) and D.Karig(1971) in terms of a hypothesis as well as the spreading - floor but suggested a discontinuous diapiric upwarping of the mantle material.

Recently the very similar ideas but more detailed and coincided with newest geophysical data was proposed to the Yamato Basin by S.Kuramoto (1991). From his means there is the isolated rise of topmost of same diapiric plume that inducing the process in terms of the stretching continental crust insures to come true the tectonic actual situations and distributions of geophysical characteristics of areas.

Before summarizing results which are looked out at previous item above it's necessary to formulate the principal conclusion as follow.

1) the exploration allow to confirm that the study region have been constructed with the strong block system of the Earth's crust. The every of those block are separated by faulting and fracture zone demonstrated above as the map of the lineaments (Fig.25) and differed on the base of their individual features, i.e. the velocity distributions, thickness of layers, the depths of the top of layers including the Moho-discontinuity and etc. The main achievements of those block pattern are the possibilities to use these for the understanding of the structural transition from the shelf and continental slope toward the seabottom of the Ulleung Basin.

2) The block pattern help also to describe the geodynamic situations which have attributed every each of them. So, the lowest or negative intensity of magnetic anomalous field have been met only over

the blocks where the high Heat Flow was measured (Fig.11).

3) The gravymetric Bouger anomalies are just closely related to the upwarping of the mantle mass creating the prolonged oval being extended along NE-SW trend,i.e the preservation of the principal relative directions of the tectonic zone of the Korean Peninsula but was accompanied by a bit degree of the clockwise rotation relatively of those.

Besides the gravymetric modeling and the seismic velocity under Moho-discontinuity show that the uplifting this interface was caused of the elevation mainly strong and hard density mantle materials because the fixed high Heat Flow over this area can't sufficiently decreased the geophysical parameters as the velocities and densities relatively to the contiguous blocks (Fig.10,11 ; Line Ⅰ and Ⅱ). It seems that the same situation are possible if the mantle mass are the ultramaphic while under the neighbor blocks the basal substance was mainly intruded.

4) Over the uplifting of mantle swell are established the high Heat Flow anomalous, the steep negative magnetic anomalous, the existence of transitive velocity thickness and etc but the structure of the sediment cover appear to occur the weak response due to this upwarping. The sediment Basin discussed widely above are produced the fulling depression of basement coming after the tectonic movements which have been pointed out inland and offshore of the Korean Peninsula and over the Kyushu Islands.

5) The established fracture zones FZ1 and FZ2 evidently are the clue structures because they are the superpositive structure replaying on the newest geodynamic processes. Considerably that over FZ1 are established the anomalous zone of the all geophysical methods. So,the high Heat Flow, The High Conductivity Layer on the depth 8 -10 km, width full zone of the uplifting of the Curie isotherm (Fig.11 ; Line Ⅱ) and sharply changing of seismic velocity are fully evidenced that this

fracture zone appear to be very young. The calculation show that this High Conductivity Zone appear to occur the 400-550 C of temperature and to be available about 0.15 -0.30 of the water fluid,i.e. the hydrodynamic processes in this area are apparently became true. What is more over this FZ1 are strongly revealed the narrow block attributing the significant low density (Fig.?????) and supporting the opinion about the development here of the jointing processes which may in any cases being accompanied by the multiple dike filling. From this viewpoint the fracture zone FZ 2 are the most oldest. Both fracture zone are not parallel to trend of the upwarping of the Moho-discontinuity but apparently are the northern extending of the Tsushima - Goto Fracture Zone.

6) Both the Heat Flow measurements and the magnetovariation data allow to point out that under the Ulleung Basin exist the anomalous low velocity zone caused of the high temperatures which may approach to 1200 C-1400 . These features evidence that the determined by seismological exploration about thinning lithosphere under the East Sea are here taking place on the depth 25-30 km. Based on the conclusion suggested above it may to assume that the Ulleung Basin apparently contains the main features of both opposite mechanisms: first , the determined shift of sea-floor along the Japan sea opening (based on the structure of uppermost low velocity sediment cover) essentially on the western area along Fracture Zone parallel to the Yangsang Fault in South Korea (Lallemand and Jolivet,1986; Yoon and Chouhg,1992) and are characterized either right or left strike - slip lateral movements;

Beside those movements always was showing as well aspolycyclic these and changing the type from right to left and reverse (Kang,1981); and second- the assumed tending of main basic structures of eastnortheast - southeast Korea Peninsula seaward and stable location or preserved its actual outline of the Ulleung sediment Basin in range of long historic time. It's considerable that on this stage of investigate of tectonic patterns of the Ulleung Basin is more real to propose the uniting mechanism as so it was suggested to Yamato Basin origin(Tatsumiet.al.,1988;Kuramoto,1991) and assume that the features of fault systems covering the Ulleung Basin is more come true in the terms of topmost of the local heated rise which uplifting and sinking here in polycycle manner as well as tectonic movements developed oncontiguous vicinity including land areas.

However and these would eventually be proven as further complexity and more detail study the conjugation of the Korean Peninsula structures and same of the sea-floor are made the some speculative considerations needed to put up.To coincide the all features it's seen to assume nor only the uplifting of this heated rise-plume but else to require the existence of the progressively southward movements its as well as it considered to Japan Islands. In this case the slip - go on horse -back the Ulleung Basin (and perhaps the same other similar) using this moving plume as escalator tape have been shifted step by step without the slightly folding and visible destruction.

This declaration requires the obviously small clock-wise rotation of the eastern edge of the Ulleung Basin according to slip moving along its showed above both the western and eastern fracture boundaries - destrictions. From this interpretation the same drawbridge ensures the right lateral movements on back-plume side and left of that on the front plume area since on the uplift stage- the pull apart stage-and reverse displacements until the rise-plume begins to cool and to sink -the backrebound stage.

In any cases it's seen evidently to understand that crucial goals of the near-future study would like to conduct on the conjugation area between the Korean Peninsula and the Ulleung western edge and the

Korean Plateau respectively.

7-3. FINAL REMARKS

The maps of principal fracture and faulting lineaments around the Ulleung Basin and its vicinity have been compiled. From those it is seen that trending of the Okcheon Fold Belt seaward may have to be assumed. The analyzing of all available evidences are pointedout that actual location of the Ulleung sediment Basin is caused of both movements: one of them step by step the slipping in east southward according to major direction and a small clock-wise rotation according to the conjugation with tectonic movements on the Korean Peninsula. The principal mechanism which supports all tectonic evolution features may have to be proposed as the uplifting of heated upwarping-plume which was being accompanied by the stretching of the crust.

7-4. CONCLUSION AND RECOMMENDATION

It's seen that the provided co-work's investigations of theUlleung Basin Area are evidently to be sufficient in the terms of the understanding of tectonic situations and evaluations of this Areas and the whole East Sea, respectively. Of course the made out results are preliminary viewpoint on this stage of study and only permitted to formulate the main goals of co-work in future.

Part of those are possible to summarize as follow:

1. It's established that the Ulleung Basin consists from two independent areas was separated by so-called UlleungInterpolate Gap (UIG). The southern-central parts of the basic Ulleung Basin situated

the south from UIG the deepest fulfilled sediment basin have been explored and have been determined that the conditions of fulfilling process here were existed since Later Cretaceous - Early Paleogene and the actual outline in duration of those times were preserved.

2. The existence of fulfilled conditions of the deepest sediment basin since Mesozoic ages on area that extends along the eastern offshore of the Korean Peninsula and coincides to the location of extension of the Korea-Tsushima straits had reliably been ascertained. It's seems to come true that of the southwestern margin of the Ulleung Basin are presented the north-northeastern circuit of that sediment basin above until before the Ulleung Basin started to rotate by the clock-wise tectonic movenents since the Miocene time.

3. The Ulleung Basin are presented the triple conjugated area where the Korean inland tectonic movements have been showed on the background of the uplifting heated upwarping-plume that step by step was being moved toward according to the Japan Islands in polycyclic manners and was accompanied with volcanic activities.

4. The polycyclic the right and left lateral movements along the powerful fracture zone that had situated on the northeastern coastline of the Korean Peninsula are established by tracing of the seaward trending the Okcheon Fold Belt as well as the Korean Plateau extension on the East Sea Area.

5. The crustal structure of the Oolong Basin on topmost are well coincided with that of Mesozoic sediment Basin of the Tsushima -Korea straits area and eastern offshore of the Korean Peninsula as above and the lowermost contains the influence of newest tectonic processes and volcanic activities. The total thickness of the Ulleung Basin crust are determined about 15-18 km (including the water depths) and very similar to those of the Yamato Basin as well as the velocity distributions and layering of both Basin are like concurred.

The ledge of Moho - discontinuity on the central parts of the Ulleung Basin are caused of volcanic activities on near by the Uleung-do and Dok-do Islands area and the depression remarked on the lower part of the continental crust. The lates follows from total low velocity in whole crust and from the structure of topmost of its.

The buried narrow and gentle rises been fixed by multichannel seismic resulting may have to induce the control to the features of the lateral movements of the Ulleung Area from the Korean Peninsula coast. The maden refraction survey over the eastern shelf and the continental slope are also confirmed these suggestions including the applicative fracture zones FZ1 and FZ2.

These features are not to conform with predicted spreading center in the term of the means by T. Hilde and J. Wagemam(1973).Of course the contemplating above would be like to examine infuture co-work researches. The main recommendations to the follow investigations are as follow:

1.The principal and crucial areas of the following investigations are the regions of the coast transition zones betweesn the Korean Peninsula and sea-floor of the East Sea. The determination of the extending of the inland structures seaward and understanding of those conjugation are basic goals of the future-nearest researches. The significant attentions are affirmed to acquire the irrefutable proofs on the tectonic movements over the sea-floor in respect to the Korean Peninsula tectonic movements zones.

2. The all seaward and offshore geophysical survey are be connected and accompanied with those of inland geophysical and geological survey by conducting the mutual Land-Marine researching lines and simultaneous measurements.

3. After the refracted survey over the Line 111 and 1V situated

on the offshore Pohang Basin have been showed that the conclusion about non-perspective of this Basin in the term of the "economically important hydrocarbon accumulations within " its(Schluter and Chun,1974; p.) are premature because at the last time " Japan Petroleum Exploration Corporation (JAPEX) discovered recently the oil and gas field in Yufutsu area,Hokkaido,Japan.Results of well test in this area show the significant and remarkable oil and gas production from the Paleogene conglomerate and the Early Cretaceous granite"(Yamazaki and Tanaka,1993; p 6). It's submitted that the strongly correlation between the Korean geologic formations and those of Japan are instilled into hope at the something better forecasts.

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